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PATENT

TO ALL WHOM IT MAY CONCERN:

Be it known that I, Gwong-Jen J. Chang, a citizen of the United States of America, residing at 4237 Beaver Creek Drive, Ft. Collins, CO 80526, U.S.A., have invented new and useful improvements in

NUCLEIC ACID VACCINES FOR PREVENTION OF FLAVIVIRUS INFECTION

for which the following is a specification.

NUCLEIC ACID VACCINES FOR PREVENTION OF FLAVIVIRUS INFECTION

This application is a continuation-in-part of, and claims the benefit of, U.S. application Serial No. 09/701,536, filed November 29, 2000, which status is pending and which is a national stage application of international application Serial No. PCT/US99/12298, filed June 3, 1999 from U.S. provisional application Serial No. 60/087908, filed June 4, 1998, which applications are hereby incorporated herein in their entirety by reference.

Field of the Invention

This invention relates to novel vaccines, diagnostics and methods of using both in the treatment and prevention of the diseases caused by flaviviruses. In particular, the vaccines are recombinant nucleic acids which contain genes for structural proteins of flaviviruses, such as Japanese encephalitis virus (JEV), West Nile virus (WNV) or related flaviviruses. These vaccines serve as a transcriptional unit for the biosynthesis of the virus protein antigens when administered *in vivo*. The diagnostics are compositions containing antigens produced from the recombinant nucleic acids that can be used to detect flavivirus infection.

Background of the Invention

Flaviviruses are members of the genus *Flavivirus*, which is classified within the family Flaviviridae. The flaviviruses are largely pathogenic to humans and other mammals. Flaviviruses that inflict disease upon humans and animals include Alfuy, Apoi, Aroa, Bagaza, Banzi, Batu Cave, Bouboui, Bukalasa bat, Bussuquara, Cacipacore, Carey Island, Cowbone Ridge, Dakar bat, Dengue (serotypes 1, 2, 3 and 4), Edge Hill, Entebbe bat, Gadgets Gully, Iguape, Ilheus, Israel turkey

meningoencephalitis, Japanese encephalitis, Jugra, Jutiapa, Kadam, Karshi, Kedougou, Kokobera, Koutango, Kunjin, Kyasanur Forest disease, Langat, Meaban, Modoc, Montana myotis leukoencephalitis, Murray Valley encephalitis, Naranjal, Negishi, Ntaya, Omsk hemorrhagic fever, Phnom Penh bat, Potiskum, Powassan, Rio Bravo, Rocio, Royal Farm, Russian spring summer encephalitis, Saboya, Sal Vieja, San Perlita, Saumarez Reef, Sepik, Sokuluk, Spondweni, St. Louis encephalitis, Stratford, Tick-borne encephalitis - central European subtype, Tick-borne encephalititis - far eastern subtype, Tembusu, THCAr, Tyuleniy, Uganda S, Usutu, West Nile, Yaounde, Yellow fever, Yokose, Ziki, Cell fusing agent and other related flaviviruses, as listed in Kuno et al. (*J. Virol.* 72: 73-83 (1998)).

The flaviviruses contain the following three structural proteins: prM/M, the premembrane and membrane protein; E, the envelope protein; and C, the capsid protein. (Monath, in <u>Virology</u> (Fields, ed.), Raven Press, New York, 1990, pp. 763-814; Heinz and Roehrig, in <u>Immunochemistry of Viruses II: The Basis for Serodiagnosis and Vaccines</u> (van Regenmortel and Neurath, eds.), Elsevier, Amsterdam, 1990, pp. 289-305). M has a molecular weight (MW) of about 7-8 kilodaltons (kDa) and E has a MW of about 55-60 kDa. M is synthesized as a larger precursor termed prM. The pr portion of prM is removed when prM is processed to form M protein in mature virions. M and E are located in the membrane of the flavivirus particle, and so have long been considered to constitute important immunogenic components of the viruses.

The flaviviruses are RNA viruses comprising single stranded RNA having a length, among the various species, of about 10 kilobases (kb). The C protein, with a MW of 12-14 kDa, complexes with the RNA to form a nucleocapsid complex. Several nonstructural proteins are also encoded by the RNA genome which are termed NS1, NS2A, NS2B, NS3, NS4A, NS4B and NS5. The genome is translated within the host cell as a polyprotein, then processed co- or post-translationally into the individual gene products by viral- or host-specific proteases (Figure 1).

The nucleotide sequences of the genomes of several flaviviruses are known, as summarized in U. S. Patent No. 5,494,671. That for JEV is provided by Sumiyoshi et al. (*Virology* 161: 497-510 (1987)) and Hashimoto et al. (*Virus Genes* 1: 305-317 (1988)). The nucleotide sequences of the virulent strain SA-14 of JEV and the attenuated strain SA-14-14-2, used as a vaccine in the People's Republic of China, are compared in the work of Nitayaphan et al. (*Virology* 177: 541-552 (1990)).

Nucleotide sequences encoding the structural proteins of other flavivirus species are also known. In many cases, the sequences for the complete genomes have been reported. The sequences available include dengue serotype 1 virus, dengue serotype 2 virus (Deubel et al., *Virology* 155: 365-377 (1986); Gruenberg et al., *J. Gen. Virol.* 69: 1391-1398 (1988); Hahn et al. *Virology* 162: 167-180 (1988)), dengue serotype 3 virus (Osatomi et al., *Virus Genes* 2: 99-108 (1988)), dengue serotype 4 virus (Mackow et al., *Virology* 159: 217-228 (1987), Zhao et al., *Virology* 155: 77-88 (1986)), West Nile virus (Lanciotti et al., *Science* 286: 2331-2333 (1999)), Powassan virus (Mandl et al., *Virology* 194: 173-184 (1993)) and yellow fever virus (YFV) (Rice et al., *Science* 229: 726-733 (1985)).

Many flaviviruses, including St. Louis encephalitis virus (SLEV), WNV and JEV, are transmitted to humans and other host animals by mosquitoes. They therefore occur over widespread areas and their transmission is not easily interrupted or prevented.

West Nile fever is a mosquito-borne flaviviral infection that is transmitted to vertebrates primarily by various species of *Culex* mosquitoes. Like other members of the Japanese encephalitis (JE) antigenic complex of flaviviruses, including JE, SLE and Murray Valley encephalitis (MVE) viruses, WNV is maintained in a natural cycle between arthropod vectors and birds. The virus was first isolated from a febrile human in the West Nile district of Uganda in 1937 (Smithburn et al., *Am. J. Trop. Med. Hyg.* 20: 471-492 (1940)). It was soon recognized as one of the most widely distributed

flaviviruses, with its geographic range including Africa, the Middle East, Western Asia, Europe and Australia (Hubalek et al., *Emerg. Infect. Dis.* 5: 643-50 (1999)). Clinically, West Nile fever in humans is a self-limited acute febrile illness accompanied by headache, myalgia, polyarthropathy, rash and lymphadenopathy (Monath and Tsai, in <u>Clinical Virology</u>, (Richman, Whitley and Hayden eds.), Churchill-Livingtone, New York, 1997, pp. 1133-1186). Acute hepatitis or pancreatis has been reported on occasion and cases of WNV infection in elderly patients are sometimes complicated by encephalitis or meningitis (Asnis et al., *Clin. Infect. Dis.* 30: 413-418 (2000)). Thus, infection by WNV is a serious health concern in many regions of the world.

The geographical spread of the disease, particularly the introduction of WNV into the U.S. in 1999, has greatly increased awareness of the human and animal health concerns of this disease. Between late August and early September 1999, New York City and surrounding areas experienced an outbreak of viral encephalitis, with 62 confirmed cases, resulting in seven deaths. Concurrent with this outbreak, local health officials observed increased mortality among birds (especially crows) and horses. The outbreak was subsequently shown to be caused by WNV, based on monoclonal antibody (Mab) mapping and detection of genomic sequences in human, avian and mosquito specimens (Anderson et al., *Science* 286: 2331-2333 (1999); Jia et al., *Lancet* 354: 1971-1972 (1999); Lanciotti et al., *Science* 286: 2333-2337 (1999)). Virus activity detected during the ensuing winter months indicated that the virus had established itself in North America (*Morb. Mortal. Wkly. Rep.* 49: 178-179 (2000); Asnis et al., *Clin. Infect. Dis.* 30: 413-418 (2000); Garmendia et al., *J. Clin. Micro.* 38: 3110-3111 (2000)). Surveillance data reported from the northeastern and mid-Atlantic states during the year 2000 confirmed an intensified epizootic/epidemic transmission and a geographic expansion of the virus with documentation of numerous cases of infection in birds, mosquitoes and horses, as well as cases in humans (*Morb. Mortal. Wkly. Rep.* 49: 820-822 (2000)).

Currently, no human or veterinary vaccine is available to prevent WNV infection and mosquito control is the only practical strategy to combat the spread of the disease.

Japanese encephalitis virus (JEV) infects adults and children and there is a high mortality rate among infants, children and the elderly in areas of tropical and subtropical Asia (Tsai et al., in Vaccines (Plotkin, ed.) W.B. Saunders, Philadelphia, Pa, 1999, pp. 672-710). Among survivors, there are serious neurological consequences, related to the symptoms of encephalitis, that persist after infection. In more developed countries of this region, such as Japan, the Republic of China (Taiwan) and Korea, JEV has been largely controlled by use of a vaccine of inactivated JEV. Nevertheless, it is still prevalent in other countries of the region.

Vaccines available for use against JEV infection include live virus inactivated by such methods as formalin treatment, as well as attenuated virus (Tsai et al., in Vaccines (Plotkin, ed.) W.B. Saunders, Philadelphia, Pa, 1994, pp. 671-713). Whole virus vaccines, although effective, do have certain problems and/or disadvantages. The viruses are cultivated in mouse brain or in cell culture using mammalian cells as the host. Such culture methods are cumbersome and expensive. Furthermore, there is the attendant risk of incorporating antigens from the host cells, i.e., the brain or other host, into the final vaccine product, potentially leading to unintended and undesired allergic responses in the vaccine recipients. There is also the risk of inadvertent infection among workers involved in vaccine production. Finally, there is the risk that the virus may not be fully or completely inactivated or attenuated and thus, the vaccine may actually cause disease.

Dengue fever and dengue hemorrhagic fever (DF/DHF) are caused by dengue virus, which is also a mosquito-borne flavivirus. There are four antigenically related, but distinct, dengue virus serotypes, (DEN-1, DEN-2, DEN-3 and DEN-4), all of which can cause DF/DHF. Symptoms of DF, the mild form of dengue-related disease, include

fever, rash, severe headache and joint pain. Mortality among those subjects suffering from DF is low; however, among those subjects suffering from DHF, mortality can be as high as 5%. From available evidence, more than 3 million cases of DHF and 58,000 deaths have been attributed to DHF over the past 40 years, making DHF a major emerging disease (Halstead, in Dengue and Dengue Hemorrhagic Fever (Gubler and Kuno, eds.) CAB International, New York, NY, (1997) pp 23-44). Nevertheless, despite decades of effort, safe and effective vaccines to protect against dengue virus infection are not yet available.

Yellow fever is prevalent in tropical regions of South America and sub-Saharan Africa and is transmitted by mosquitos. Infection leads to fever, chills, severe headache and other pains, anorexia, nausea and vomiting, with the emergence of jaundice. A live virus vaccine, 17D, grown in infected chicken embryos, is considered safe and effective. Nevertheless, there remains a need for a vaccine that is stable under adverse conditions, such as are commonly encountered in the tropical regions of Africa and the Americas where the vaccine is most needed.

A recombinant flavivirus which is a chimera between two flaviviruses is disclosed in PCT publication WO 93/06214. The chimera is a construct fusing non-structural proteins from one "type," or serotype, of dengue virus or a flavivirus, with structural proteins from a different "type," or serotype, of dengue virus or other flavivirus.

Several recombinant subunit and viral vaccines have been devised in recent years. U. S. Patent No. 4,810,492 describes the production of the E glycoprotein of JEV for use as the antigen in a vaccine. The corresponding DNA is cloned into an expression system in order to express the antigen protein in a suitable host cell such as *E. coli*, yeast, or a higher organism cell culture. U. S. Patent No. 5,229,293 discloses recombinant baculovirus harboring the gene for JEV E protein. The virus is used to

infect insect cells in culture such that the E protein is produced and recovered for use as a vaccine.

U. S. Patent No. 5,021,347 discloses a recombinant vaccinia virus genome into which the gene for JEV E protein has been incorporated. The live recombinant vaccinia virus is used as the vaccine to immunize against JEV. Recombinant vaccinia viruses and baculoviruses in which the viruses incorporate a gene for a C-terminal truncation of the E protein of dengue serotype 2, dengue serotype 4 and JEV are disclosed in U.S. Patent 5,494,671. U. S. Patent 5,514,375 discloses various recombinant vaccinia viruses which express portions of the JEV open reading frame extending from prM to NS2B. These pox viruses induced formation of extracellular particles that contain the processed M protein and the E protein. Two recombinant viruses encoding these JEV proteins produced high titers of neutralizing and hemagglutinin-inhibiting antibodies, and protective immunity, in mice. The extent of these effects was greater after two immunization treatments than after only one. Recombinant vaccinia virus containing genes for the prM/M and E proteins of JEV conferred protective immunity when administered to mice (Konishi et al., *Virology* 180: 401-410 (1991)). HeLa cells infected with recombinant vaccinia virus bearing genes for prM and E from JEV were shown to produce subviral particles (Konishi et al., *Virology* 188: 714-720 (1992)). Dmitriev et al. reported immunization of mice with a recombinant vaccinia virus encoding structural and certain nonstructural proteins from tick-borne encephalitis virus (*J. Biotechnology* 44: 97-103 (1996)).

Recombinant virus vectors have also been prepared to serve as virus vaccines for dengue fever. Zhao et al. (*J. Virol.* 61: 4019-4022 (1987)) prepared recombinant vaccinia virus bearing structural proteins and NS1 from dengue serotype 4 and achieved expression after infecting mammalian cells with the recombinant virus. Similar expression was obtained using recombinant baculovirus to infect target insect cells (Zhang et al., *J. Virol.* 62: 3027-3031(1988)). Bray et al. (*J. Virol.* 63: 2853-2856 (1989)) also reported a recombinant vaccinia dengue vaccine based on the E protein

gene that confers protective immunity to mice against dengue encephalitis when challenged. Falgout et al. (*J. Virol* 63: 1852-1860 (1989)) and Falgout et al. (*J. Virol.* 64: 4356-4363 (1990)) reported similar results. Zhang et al. (*J. Virol* 62: 3027-3031 (1988)) showed that recombinant baculovirus encoding dengue E and NS1 proteins likewise protected mice against dengue encephalitis when challenged. Other combinations in which structural and nonstructural genes were incorporated into recombinant virus vaccines failed to produce significant immunity (Bray et al., *J. Virol.* 63: 2853-2856 (1989)). Also, monkeys failed to develop fully protective immunity to dengue virus challenge when immunized with recombinant baculovirus expressing the E protein (Lai et al. (1990) pp. 119-124 in F. Brown, R. M. Chancock, H. S. Ginsberg and R. Lerner (eds.) <u>Vaccines 90: Modern approaches to new vaccines including prevention of AIDS</u>, Cold Spring Harbor Laboratory, Cold Spring Harbor, NY).

Immunization using recombinant DNA preparations has been reported for SLEV and dengue-2 virus, using weanling mice as the model (Phillpotts et al., *Arch. Virol.* 141: 743-749 (1996); Kochel et al., *Vaccine* 15: 547-552 (1997)). Plasmid DNA encoding the prM and E genes of SLEV provided partial protection against SLEV challenge with a single or double dose of DNA immunization. In these experiments, control mice exhibited about 25% survival and no protective antibody was detected in the DNA-immunized mice (Phillpotts et al., *Arch. Virol.* 141: 743-749 (1996)). In mice that received three intradermal injections of recombinant dengue-2 plasmid DNA containing prM, 100% developed anti-dengue-2 neutralizing antibodies and 92% of those receiving the corresponding E gene likewise developed neutralizing antibodies (Kochel et al., *Vaccine* 15: 547-552 (1997)). Challenge experiments using a two-dose schedule, however, failed to protect mice against lethal dengue-2 virus challenge.

The vaccines developed to date for immunizing against infection by JEV, SLEV, dengue virus and other flaviviruses have a number of disadvantages and problems attending their use. Inactivated vaccine is costly and inconvenient to prepare. In addition, any such vaccine entails the risk of allergic reaction originating from

proteins of the host cell used in preparing the virus. Furthermore, such vaccines present considerable risk to the workers employed in their production. Candidate attenuated JEV vaccines are undergoing clinical trials, but as of 1996 have not found wide acceptance outside of the People's Republic of China (Hennessy et al., *Lancet* 347: 1583-1586 (1996)).

Recombinant vaccines based on the use of only certain proteins of flaviviruses, such as JEV, produced by biosynthetic expression in cell culture with subsequent purification or treatment of antigens, do not induce high antibody titers. Also, like the whole virus preparations, these vaccines carry the risk of adverse allergic reaction to antigens from the host or to the vector. Vaccine development against dengue virus and WNV is less advanced and such virus-based or recombinant protein-based vaccines face problems similar to those alluded to above.

There is therefore a need for vaccines or improved vaccines directed against flaviviruses such as yellow fever virus, dengue virus, JEV, SLEV and WNV which are inexpensive to prepare, present little risk to workers involved in their manufacture, carry minimal risk of adverse immunological reactions due to impurities or adventitious immunogenic components and are highly effective in eliciting neutralizing antibodies and protective immunity. There is furthermore a need for a vaccine against JEV, WNV and related flaviviruses that minimizes the number of immunizing doses required.

Many of the shortcomings of the current art as described in detail for the production of vaccines also apply to the production of antigens and antibodies to be used for the production of immunodiagnostics. Particularly, the concurrent risks and costs involved in the production of antigens from viruses and the failure of most currently available recombinantly expressed antigens to elicit effective immune responses are paralleled in the field of immunodiagnostics by the same risks, high costs and a corresponding lack of sensitivity. Thus, because of the high costs, risk of accidental infection with live virus and the lower than desired levels of sensitivity of

the previously available tests, there exists a need for rapid, simple and highly sensitive diagnostic tests for detecting flavivirus infection and/or contamination.

The present invention meets these needs by providing highly immunogenic recombinant antigens for use in diagnostic assays for the detection of antibodies to selected flaviviruses. The present invention further provides for the use of recombinant antigens derived from flaviviruses, flavivirus genes or mimetics thereof in immunodiagnostic assays for the detection of antibodies to flavivirus proteins.

Summary of the Invention

The present invention provides a nucleic acid molecule which contains a transcriptional unit (TU) for an immunogenic flavivirus antigen. The TU directs a host cell, after being incorporated within the cell, to synthesize the antigen. In an important aspect of the invention, the flavivirus can be yellow fever virus (YFV), dengue serotype 1 virus (DEN-1), dengue serotype 2 virus (DEN-2), dengue serotype 3 virus (DEN-3), dengue serotype 4 virus (DEN-4), St. Louis encephalitis virus (SLEV), Japanese encephalitis virus (JEV), West Nile virus (WNV), Powassan virus or any other flavivirus. In important embodiments of the present invention, the antigen can be the flavivirus prM/M protein, the E protein, or both. In particular, when the TU includes both the prM/M and E proteins, the host cell secretes subviral particles containing the prM/M and E antigens. In a further important aspect of the invention, the nucleic acid is a DNA molecule. In additional significant embodiments, the nucleic acid TU includes a control sequence disposed appropriately such that it operably controls the expression of the prM/M and E antigens and this control sequence can be the cytomegalovirus immediate early promoter. In an additional embodiment, the nucleotide sequence of the TU is engineered to optimize eukaryotic translation by minimizing large hairpin structures in the 5'-end untranslated region of an mRNA produced by the TU and/or the inclusion of a Kozak consensus sequence at the

translational start site of an mRNA produced by the TU. In an additional embodiment, the transcriptional unit also includes a poly-A terminator.

The present invention further provides a host cell comprising a nucleic acid molecule which includes a transcriptional unit for an immunogenic flavivirus antigen that directs the host cell to synthesize the immunogenic antigen. The flavivirus may be YFV, DEN-1, DEN-2, DEN-3, DEN-4, SLEV, JEV, WNV, Powassan virus or other flavivirus. In important embodiments, the antigen may be the prM/M protein, the E protein, or both the prM/M and the E proteins. In the latter case, the cell secretes subviral particles containing the prM/M and E antigens.

Additionally, the invention provides a composition for vaccinating a subject against a flavivirus containing a nucleic acid molecule that includes a transcriptional unit for an immunogenic flaviviral antigen. The transcriptional unit directs a cell within the body of the subject, after being incorporated therein, to synthesize the immunogenic antigen. The composition further includes a pharmaceutically acceptable carrier. In significant embodiments, the flavivirus may be YFV, DEN-1, DEN-2, DEN-3, DEN-4, SLEV, JEV, WNV, Powassan virus or other flavivirus. Furthermore, the antigen may be the prM/M protein, the E protein, or both the prM/M and the E proteins. In the latter instance, the cell secretes subviral particles comprising the flavivirus prM/M and E antigens. These subviral particles are also referred to as noninfectious recombinant antigen (NRA). In important embodiments, the nucleic acid molecule is a DNA molecule. In further significant embodiments, the transcriptional unit additionally contains a control sequence disposed appropriately such that it operably controls the synthesis of the prM/M and E antigens when the nucleic acid is introduced into the cell of the subject. This control sequence can be the cytomegalovirus immediate early promoter. In a still further embodiment, the transcriptional unit can also include a poly-A terminator.

The invention provides still further a method of immunizing a subject against infection by a flavivirus. The method involves administering to the subject an effective amount of a vaccinating composition that contains a nucleic acid molecule which includes a transcriptional unit for an immunogenic flavivirus antigen. The transcriptional unit directs a cell within the body of the subject, after being taken up by the cell, to synthesize the immunogenic antigen. The composition additionally includes a pharmaceutically acceptable carrier. In significant embodiments of the method, the flavivirus may be YFV, DEN-1, DEN-2, DEN-3, DEN-4, SLEV, JEV, WNV, Powassan virus or other flavivirus. In yet other important aspects of the method, the antigen may be the prM/M protein, the E protein, or both the prM/M and the E proteins. When the antigen is both the prM/M and the E proteins, the cell within the body of the subject, after incorporating the nucleic acid within it, secretes subviral particles comprising the flaviviral prM/M and E antigens. Additionally, in significant embodiments of the method, the vaccinating composition is administered to the subject in a single dose, via a parenteral route. In yet a further aspect of the method, the nucleic acid is a DNA molecule. In yet additional embodiments of the method, the transcriptional unit further includes a control sequence disposed appropriately such that it operably controls the synthesis of the prM/M and E antigens and in a significant aspect of this embodiment, the control sequence is the cytomegalovirus immediate early promoter. Furthermore, the transcriptional unit may include a poly-A terminator.

These aspects and embodiments of the invention are the basis for its distinct attributes and advantages. Being a nucleic acid construct involving only portions of the flavivirus genome rather than the sequence encompassing the complete genome, the nucleic acid TU-containing vaccine is completely nonviable. It therefore poses no danger of infection by the flavivirus to those involved in its manufacture or to subjects receiving the vaccine. The nucleic acid vaccine is easy to prepare and easy to administer and is stable in storage prior to use. Unexpectedly it has been found that the nucleic acid vaccine of the invention is essentially 100% successful in conferring protective immunity in mammals after administering only a single dose. A further

unexpected result is that the nucleic acid TU is able to engender immunity to a flavivirus in a female mammal which can be transmitted to its progeny through the milk. Without wishing to be limited by theory, the inventor believes that a possible mechanism for the success of the nucleic acid in conferring protective immunity is that a host cell harboring the nucleic acid, such as the cell of a subject to whom the vaccine is administered, produces subviral particles containing the flaviviral prM/M and E antigens. These particles mimic the immunogenic attributes of native flavivirus virions.

The present invention also provides noninfectious antigenic polypeptides, antigenic polypeptide fragments and NRA comprising the prM/M and/or E proteins of flaviviruses, wherein the transmembrane signal sequence is derived from a first flavivirus and the M and/or E proteins are derived from a second flavivirus. Further, the prM/M protein can comprise amino acid sequences from both the first and the second flaviviruses. "Chimeric" as used herein means any protein or nucleic acid comprising sequence from more than one flavivirus. As used herein, "non-virulent" means the antigen or vaccine of this invention is incapable of causing disease. More particularly, the recombinant protein antigens are free of contaminating genomic material from flaviviruses that is necessary for flavivirus infection, replication and pathogenesis.

The polypeptides of the present invention can comprise the amino acid sequences defined herein, or that are known in the art, of the prM, M and/or E proteins of selected flaviviruses. The nucleic acids of this invention can comprise nucleotide sequence that encodes the prM, M and/or E proteins of selected flaviviruses.

The antigens of the present invention can be unconjugated, or they can be conjugated to a carrier molecule that facilitates placement of the antigen on a solid phase. A carrier molecule is one to which antigens can be conjugated and which will

not react with antibodies in human serum. An example of such a carrier is bovine serum albumin (BSA).

The antigens of the present invention can also be recombinant proteins obtained by expressing nucleic acids encoding the antigen in an expression system capable of producing the antigen.

The amino acid sequences of the present antigens can contain an immunoreactive portion of the prM, M and/or E antigen. These antigens may further be attached to sequences designed to provide for some additional property, such as to remove/add amino acids capable of disulfide bonding to increase the reactivity of an epitope by providing a more rigid secondary structure, to increase its bio-longevity or to alter its cytotoxicity or to prevent infection. In any case, the antigen must possess immunoreactivity and/or immunogenicity.

Brief Description of the Drawings

Figure 1 is a schematic representation of flaviviral polyprotein processing. The central horizontal region provides a schematic representation of the viral genome. The lines denote the 5' and 3' non-translated regions and the boxed regions represent the open reading frame for structural (left and top) and non-structural (right and bottom) proteins. Cleavage by host cell signalase occurs simultaneously with translation at the E protein C-terminus, separating structural and non-structural regions. A subtilase-like cellular enzyme, furin, may be responsible for prM cleavage. Potential transmembrane domains of viral polyprotein are indicated by shaded areas.

Figure 2 is a map of the JEV genome (top) and the DNA sequence of oligonucleotides used in a reverse transcriptase-polymerase chain reaction (RT-PCR) (center) to construct the transcription unit for the expression of prM-E protein coding regions (bottom). Potential transmembrane domains of viral polyprotein are indicated by shaded areas.

Figure 3 shows a schematic representation of the plasmid vectors, pCDNA3, pCBamp, and pCIBamp, and the relationship between them. These plasmids include the CMV (cytomegalovirus) promoter/enhancer element, BGHp(A) (bovine growth hormone polyadenylation signal and transcription termination sequence), ampicillin resistance gene and ColE1 origin of replication for selection and maintenance in *E. coli*. The f1 origin of replication for single-stranded rescue in *E. coli* cells, SV40 origin of replication (SV40 ORI), neomycin resistance coding region and SV40p(A) sequences were deleted from pCDNA3 to generate pCBamp. An intron sequence was inserted in the NcoI-KpnI site of pCBamp to generate plasmid pCIBamp.

Figure 4 shows SDS-PAGE-immunoblot analyses of the sucrose gradient purified subviral particles from JE-4B COS-1 culture fluid (4B, right lane of each pair). The density gradient purified JE virion from JEV infected C6/36 cell culture was used as a positive control (JEV, left lane of each pair). JE HIAF (hyperimmune ascitic fluid); 4G2, anti-E monoclonal antibody; JM01, anti-M monoclonal antibody; NMAF (normal mouse ascitic fluid).

Figure 5 shows a profile of the E antigen in a rate zonal sucrose gradient analysis prepared from the PEG precipitate of JE-4B cell culture medium with or without Triton X-100 treatment.

Detailed Description of the Invention

The invention encompasses nucleic acid transcriptional units which encode flaviviral antigenic proteins, such as the prM/M and E protein antigens. The nucleic acids function to express the prM/M and E protein antigens when the nucleic acid is taken up by an appropriate cell, especially when the cell is the cell of a subject. The invention also encompasses a vaccine whose active agent is the nucleic acid transcriptional unit (TU). The invention further encompasses cells containing a TU. The invention in addition encompasses a method of immunizing a subject against

flaviviral infection by administering to the subject an effective amount of a vaccine containing the nucleic acid TU molecules.

The invention provides an isolated nucleic acid comprising a transcriptional unit encoding a signal sequence of a structural protein of a first flavivirus and an immunogenic flavivirus antigen of a second flavivirus, wherein the transcriptional unit directs the synthesis of the antigen. The invention further encompasses the use of the nucleic acid transcriptional unit (TU) to generate flaviviral antigens and the flaviviral antigens produced by the nucleic acid TU. The invention still further encompasses the use of the flaviviral antigens encoded by the TU of the invention to produce flavivirus-specific antibodies and to detect the presence of flavivirus-specific antibodies.

In one embodiment, the isolated nucleic acid of this invention can comprise a transcriptional unit encoding a Japanese encephalitis virus signal sequence.

In another embodiment, the transcriptional unit of this invention can encode an immunogenic flavivirus antigen which can be from one or more of the following flaviviruses: yellow fever virus, dengue serotype 1 virus, dengue serotype 2 virus, dengue serotype 3 virus, dengue serotype 4 virus, Japanese encephalitis virus, Powassan virus and West Nile virus.

In a particular embodiment, the nucleic acid of this invention can encode a signal sequence of Japanese encephalitis virus and an M protein and an E protein of West Nile virus, SLEV, YFV and/or Powassan virus. The nucleic acid can also encode an immunogenic antigen which can be an M protein of a flavivirus, an E protein of a flavivirus, both an M protein and an E protein of a flavivirus, a portion of an M protein of a flavivirus, a portion of an E protein of a flavivirus and/or both a portion of an M protein of a flavivirus and a portion of an E protein of a flavivirus. In a preferred embodiment, the isolated nucleic acid encodes both the M protein and the E protein of the flavivirus. Further, the nucleic acid of the invention can be DNA and can comprise

nucleotide sequence SEQ ID NO:15, SEQ ID NO:19, SEQ ID NO:21 or SEQ ID NO:23.

The transcriptional unit of this invention can also comprise a control sequence disposed appropriately so that it operably controls the synthesis of the antigen. The control sequence can be, for example, the cytomegalovirus immediate early promoter. The nucleic acid of this invention can also comprise a Kozak consensus sequence located at a translational start site for a polypeptide comprising the antigen encoded by the transcriptional unit. The transcriptional unit of this invention can also comprise a poly-A terminator.

The present invention further provides a cell comprising the nucleic acid of this invention.

Also provided is a composition comprising a pharmaceutically acceptable carrier and nucleic acid or cell or antigen of this invention. The present invention additionally provides a method of immunizing a subject against infection by a flavivirus, comprising administering to the subject an effective amount of a composition of this invention. In a particular embodiment, the composition used to immunize a subject directs the synthesis of both the M protein and the E protein of a flavivirus and a cell within the body of the subject, after incorporating the nucleic acid within it, secretes subviral particles comprising the M protein and the E protein. Alternatively, the composition can comprise an M protein and/or E protein of a flavivirus or subviral particles comprising the M protein and E protein. In the methods of this invention, the immunizing composition can be administered to the subject in a single dose and can be administered via a parenteral route.

This invention further provides the antigens produced from the isolated nucleic acids of this invention. As an example, the antigen from the second flavivirus encoded by the nucleotide sequence of TU can be the M protein which can be, for example, from

West Nile virus. The antigen can also be protein from dengue virus, St. Louis encephalitis virus, Japanese encephalitis virus, Powassan virus and/or yellow fever virus. In a further embodiment, the antigen comprises a prM/M protein comprising the transmembrane signal sequence from a first flavivirus and further amino acid sequence comprising the remainder of the prM/M protein from a second flavivirus, which can be from SLEV, JEV, YFV, WNV and/or Powassan virus.

The antigen encoded by the nucleotide sequence of the TU can be West Nile virus antigen, dengue virus antigen, St. Louis encephalitis virus antigen, Japanese encephalitis virus antigen, Powassan virus antigen and/or yellow fever virus antigen.

The antigen encoded by the nucleotide sequence of the TU can also be the E protein, which can be the E protein from West Nile virus, dengue virus, St. Louis encephalitis virus, Japanese encephalitis virus, Powassan virus and/or yellow fever virus.

Additionally, the antigen encoded by the nucleotide sequence of the TU can be the M protein and the E protein, which can be from West Nile virus, dengue virus, St. Louis encephalitis virus, Japanese encephalitis virus, Powassan virus and/or yellow fever virus.

As used herein, "M protein" or "pr/M protein" or "prM/M protein" means a flavivirus M protein or flavivirus prM protein. Examples include, but are not limited to, prM proteins comprising amino acid sequence from one or more flavivirus prM proteins, M proteins comprising no additional amino acid sequence and proteins comprising additional amino acid sequences which are processed *in vitro* or *in vivo* to generate the mature M protein.

As used herein, "nucleic acid transcriptional unit" or "nucleic acid transcriptional unit molecule" means a nucleic acid encoding one or more specified

proteins. The TU has biological activity such that, after having been introduced into a suitable cell, the nucleic acid induces the synthesis of one or more specified gene products encoded by the nucleic acid. The gene product(s) is(are) other biological macromolecules, such as proteins, not chemically related to the TU. The nucleic acid TU induces the cell to employ its cellular components to produce the specific gene product or products encoded by the nucleic acid of the TU. Although any nucleic acid may serve as a TU, in a preferred embodiment, the TU is the DNA of a plasmid or similar vector, wherein the plasmid or vector comprises coding sequences of marker genes or other sequence constructions that facilitate use of the TU for experimentation and biosynthesis.

As used herein, a "control sequence" is a regulatory nucleotide sequence incorporated within a TU which interacts with appropriate cellular components of the cell and leads to enhanced or activated biosynthesis of the gene products encoded by the TU. Thus a suitable control sequence is one with which the components of the cell have the capability to interact, resulting in synthesis of the gene product. When operably disposed in a nucleic acid with respect to a specified coding sequence, a control sequence effectively controls expression of the specified nucleic acid to produce the gene product.

As used herein, a "promoter" is a nucleotide sequence in a TU which serves as a control sequence.

As used herein, a “Kozak sequence” or “Kozak consensus sequence” is a nucleotide sequence at the translational start site which optimizes translation of eukaryotic mRNAs (Kozak, *Mol. Cell. Biology* 9: 5134-5142 (1989)) .

As used herein, a "terminator" is an extended nucleotide sequence which acts to induce polyadenylation at the 3' end of a mature mRNA. A terminator sequence is found after, or downstream from, a particular coding sequence.

As used herein, a "cell" is a prokaryotic or eukaryotic cell comprising a TU coding for one or more gene products, or into which such a TU has been introduced. Thus, a cell harbors a foreign or heterologous substance, the TU, which is not naturally or endogenously found in the cell as a component. A suitable cell is one which has the capability for the biosynthesis of the gene products as a consequence of the introduction of the TU. In particular, a suitable cell is one which responds to a control sequence and to a terminator sequence, if any, that may be included within the TU. In important embodiments of the present invention, the cell is a mammalian cell. In particularly important embodiments of this invention, the cell is a naturally occurring cell in the body of a human or nonhuman subject to whom (which) the TU has been administered as a component of a vaccine. Alternatively, in analytical, or diagnostic applications, including preparation of antigen for use as a vaccine or in immunodiagnostic assays, or for demonstrative purposes, the cell may be a human or nonhuman cell cultured *in vitro*.

As used herein, a "vaccine" or a "composition for vaccinating a subject" specific for a particular pathogen means a preparation, which, when administered to a subject, leads to an immunogenic response in a subject. As used herein, an "immunogenic" response is one that confers upon the subject protective immunity against the pathogen. Without wishing to be bound by theory, it is believed that an immunogenic response may arise from the generation of neutralizing antibodies (i.e., a humoral immune response) or from cytotoxic cells of the immune system (i.e., a cellular immune response) or both. As used herein, an "immunogenic antigen" is an antigen which induces an immunogenic response when it is introduced into a subject, or when it is synthesized within the cells of a host or a subject. As used herein, an "effective amount" of a vaccine or vaccinating composition is an amount which, when administered to a subject, is sufficient to confer protective immunity upon the subject. Historically, a vaccine has been understood to contain as an active principle one or more specific molecular components or structures which comprise the pathogen, especially its surface. Such structures may include surface components such as

proteins, complex carbohydrates, and/or complex lipids which commonly are found in pathogenic organisms.

As used herein, however, it is to be stressed that the terms "vaccine" or "composition for vaccinating a subject" extend the conventional meaning summarized in the preceding paragraph. As used herein, these terms also relate to the TU of the instant invention or to compositions containing the TU. The TU induces the biosynthesis of one or more specified gene products encoded by the TU within the cells of the subject, wherein the gene products are specified antigens of a pathogen. The biosynthetic antigens then serve as an immunogen. As already noted, the TU, and hence the vaccine, may be any nucleic acid that encodes the specified immunogenic antigens. In a preferred embodiment of this invention, the TU of the vaccine is DNA. The TU can include a plasmid or vector incorporating additional genes or particular sequences for the convenience of the skilled worker in the fields of molecular biology, cell biology and viral immunology (See Molecular Cloning: A Laboratory Manual, 2nd Ed., Sambrook, Fritsch and Maniatis, Cold Spring Harbor Laboratory, Cold Spring Harbor, NY, 1989; and Current Protocols in Molecular Biology, Ausubel et al., John Wiley and Sons, New York 1987 (updated quarterly), which are incorporated herein by reference).

The TU molecules of the instant invention comprise nucleic acids, or derivatives of nucleic acids, having nucleotide sequences that encode specific gene products related to antigens of flaviviruses such as, but not limited to, WNV, JEV, dengue virus, yellow fever virus and SLEV. Although any nucleic acid may serve as a TU, in an important embodiment, the TU is DNA. Alternatively, the nucleic acids may be RNA molecules. They may also be any one of several derivatives of DNA or RNA having a backbone of phosphodiester bonds that have been chemically modified to increase the stability of the TU as a pharmaceutical agent. Modifications so envisioned include, but are not limited to, phosphorothioate derivatives or phosphonate derivatives.

These and other examples of derivatives are well known to persons skilled in the field of nucleic acid chemistry.

The genome of JEV has been characterized and sequenced (Figures 1 and 2). The M structural protein is expressed as a portion of the polyprotein which includes a pre-M sequence (pr). This pr sequence, immediately amino terminal to the M protein sequence, prevents conformational problems in the processing of the polyprotein. In particular, the presence of the pr sequence is important in preventing misfolding of the E protein. Thus, the presence of prM allows for assembly of JEV particles. Once the virion or particle is formed, the pr sequence can be cleaved from the prM protein to yield mature virus particles containing M proteins, although cleavage of the prM protein to yield M protein is not necessary to produce infectious particles. The prM sequences from many different, related flaviviruses are cleaved to but a low extent, but the flaviviruses themselves are nonetheless, infectious. Examples of such related flaviviruses with similar genomic structures and functions include, but are not limited to WNV, YFV, dengue virus and SLEV.

In one embodiment, the TU encoding flaviviral M and E proteins in the instant invention is DNA. In accord with the discussion in the preceding paragraph, this DNA comprises a nucleotide sequence which encodes the M protein, comprising the pre-M sequence, and a nucleotide sequence encoding the E protein. In this way, the intended gene products are enabled to form subviral particles within the cell. The pre-M sequence can then be cleaved in a fashion analogous to that which occurs with respect to replete virions.

In order to function effectively *in vivo* as a vaccine, it is advantageous to include within the TU a control sequence that has the effect of enhancing or promoting the transcription of the nucleotide sequences encoding the antigens. Use of such promoters is well known to those of skill in the fields of molecular biology, cell biology and viral immunology (See Molecular Cloning: A Laboratory Manual, 2nd Ed., Sambrook,

Fritsch and Maniatis, Cold Spring Harbor Laboratory, Cold Spring Harbor, NY, 1989; and Current Protocols in Molecular Biology, Ausubel et al., John Wiley and Sons, New York 1987 (updated quarterly)). When the TU is used as a vaccine in a mammalian host, the promoter to be employed is preferably one which operates effectively in mammalian cells. Such a promoter is disposed with respect to the coding sequences from which transcription is to be promoted, at a position at which it may operably promote such transcription. In a significant embodiment of the instant invention, this promoter is the cytomegalovirus early promoter. In addition, in a further preferred embodiment of the invention, the coding sequences are followed, in the TU nucleic acid, by a terminator sequence (Sambrook et al.). Particular embodiments of the invention relate to both prokaryotic and eukaryotic cells. Many promoter sequences are known that are useful in either prokaryotic or eukaryotic cells. (See Sambrook et al.)

The nucleic acids of the invention may further include DNA sequences known to those of skill in the art to act as immunostimulatory elements. Examples of such elements include, but are not limited to, certain CpG motifs in bacterial DNA (Sato et al., *Science* 273: 352-354 (1996); Klinman et al., *Vaccine* 17: 19-25 (1998)).

Preparation of the TU of the invention is readily accomplished by methods well known to workers of skill in the field of molecular biology. Procedures involved are set forth, for example, in Molecular Cloning: A Laboratory Manual, 2nd Ed., Sambrook, Fritsch and Maniatis, Cold Spring Harbor Laboratory, Cold Spring Harbor, NY, 1989 and Current Protocols in Molecular Biology, Ausubel et al., John Wiley and Sons, New York 1987 (updated quarterly). The flaviviral RNA molecule may be isolated from a sample of live virus by methods widely known among virologists familiar with flaviviruses, for example, and with other groups of viruses as well. Methods used with JEV are summarized in Kuno et al. (*J. Virol.* 72: 73-83 (1998)). The RNA is used as a template for the synthesis of cDNA using reverse transcriptase. From the cDNA, a fragment containing the pre-M through E coding region (Figure 2) is obtained by digestion with restriction nucleases known to cleave the cDNA

appropriately to provide such fragments. Examples of restriction digestion of JEV are provided in Nitayaphan et al. (1990) and Konishi et al. (1991). Incorporation of promoters, such as the cytomegalovirus promoter, sequences to promote efficient translation, such as the Kozak sequence, and of the polyadenylation signal, is likewise well known to skilled practitioners in molecular biology and recombinant DNA engineering (Kozak, *Mol. Cell. Biology* 9: 5134-5142 (1989); Azevedo et al., *Braz. J. Med. Biol. Res.* 32: 147-153 (1999)). When a nucleic acid comprising a TU containing the desired coding sequences and control sequences is prepared, it may be obtained in larger quantities by methods that amplify nucleic acids. Such methods are widely known to workers skilled in molecular biology and recombinant DNA engineering. Examples of these methods include incorporation of the nucleic acid into a plasmid for replication by culturing in a cell such as a prokaryotic cell and harvesting the plasmid after completing the culture, as well as amplification of the nucleic acid by methods such as PCR and other amplification protocols, as are well known in the art. These examples are not intended to limit the ways in which the nucleic acid containing the TU may be obtained.

The TU-containing nucleic acid molecules of the instant invention may be introduced into appropriate cells in many ways well known to skilled workers in the fields of molecular biology and viral immunology. By way of example, these include, but are not limited to, incorporation into a plasmid or similar nucleic acid vector which is taken up by the cells, or encapsulation within vesicular lipid structures such as liposomes, especially liposomes comprising cationic lipids, or adsorption to particles that are incorporated into the cell by endocytosis.

In general, a cell of this invention is a prokaryotic or eukaryotic cell comprising a TU, or into which a TU has been introduced. The TU of the present invention induces the intracellular biosynthesis of the encoded prM/M and E antigens. A suitable cell is one which has the capability for the biosynthesis of the gene products as a consequence of the introduction of the nucleic acid. In particular embodiments of the

invention, a suitable cell is one which responds to a control sequence and to a terminator sequence, if any, which may be included within the TU. In order to respond in this fashion, such a cell contains within it components which interact with a control sequence and with a terminator and act to carry out the respective promoting and terminating functions. When the cell is cultured *in vitro*, it may be a prokaryote, a single-cell eukaryote or a multicellular eukaryote cell. In particular embodiments of the present invention, the cell is a mammalian cell. In these cases, the synthesized prM/M and E protein gene products are available for use in analytical, or diagnostic applications, including preparation of antigen for use as a vaccine or in immunodiagnostic assays, or for demonstrative purposes.

In some circumstances, such as when the cell is a cultured mammalian cell, the prM/M and E antigens are secreted in the form of subviral particles. These are aggregates of prM/M and E proteins resembling live virus in surface ultrastructural morphology and immunogenic properties. Since the TU of the invention does not include the remainder of the flaviviral genome, however, there is no capsid incorporated, and most importantly, no infectious viral RNA.

In another important embodiment of this invention, the cell is a natural cellular component of the subject to whom the TU has been administered as a vaccine. The TU, when administered to the subject, is taken up by the cells of the subject. The subject's cells have the capability of responding to any promoter sequences, and terminator, if present. In any case, the TU induces the subject's cells to synthesize flaviviral prM/M and E gene products. Without wishing to be constrained by theoretical considerations, it is believed that the subject's cells produce subviral particles *in vivo* consisting of the prM/M and E antigens, just as has been found to occur with cultured mammalian cells *in vitro*. Such subviral particles, it is believed, then serve as the *in vivo* immunogen, stimulating the immune system of the subject to generate immunological responses which confer protective immunity on the subject. Again without wishing to be limited by theory, the resulting protective immunity may

arise via either humoral or cellular immunity, i.e., via either an MHC class II- or class I-restricted mechanism, respectively, or by both mechanisms.

According to the invention, subjects are immunized against infection by flaviviruses, such as JEV, YFV, dengue virus, SLEV, WNV or other flaviviruses by administering to them an effective amount of a TU comprising nucleic acid which encodes the prM and/or E antigens. The nucleic acid, after being incorporated into the cells of the subject, leads to the synthesis of the flaviviral prM/M and/or E antigens.

In order to administer the TU to the subject, it is incorporated into a composition which comprises a pharmaceutically acceptable carrier. The term "pharmaceutically acceptable" means a material that is not biologically or otherwise undesirable, i.e., the material may be administered to an subject along with the immunogenic material (i.e., recombinant flavivirus protein antigens or portions thereof) without causing any undesirable biological effects or interacting in a deleterious manner with any of the other components of the vaccine in which it is contained. Examples of pharmaceutically acceptable carriers, or components thereof, include water, physiological saline and common physiological buffers (for further examples, see Arnon, R. (Ed.) Synthetic Vaccines I: pp. 83-92, CRC Press, Inc., Boca Raton, Florida, 1987).

It is understood by those skilled in the art that the critical value in describing a vaccination dose is the total amount of immunogen needed to elicit a protective response in a host which is subject to infectious disease caused by virulent or wild-type flavivirus infection. The number and volume of doses used can be varied and are determined by the practitioner based on such parameters as, age, weight, gender, species, type of vaccine to be administered, mode of administration, overall condition of the subject, et cetera, as well as other important factors recognized by those of skill in the art.

The TU may be administered to a subject orally, parenterally (e.g., intravenously), by intramuscular injection, by intraperitoneal injection, transdermally, extracorporeally, intranasally, topically or the like. Delivery can also be directly to any area of the respiratory system (e.g., lungs) via intubation. The exact amount of the TU required will vary from subject to subject, depending on the species, age, weight and general condition of the subject, the immunogenicity of the vaccine used, the strain or species of flavivirus against which the subject is being immunized, the mode of administration and the like. Thus, it is not possible to specify an exact amount for every embodiment of the present invention. However, an appropriate amount can be determined by one of ordinary skill in the art using only routine experimentation given the teachings herein and what is available in the art.

Parenteral administration of the vaccine of the present invention, if used, is generally characterized by injection. Injectables can be prepared in conventional forms, either as liquid solutions or suspensions, solid forms suitable for solution or suspension in liquid prior to injection, or as emulsions. A more recently revised approach for parenteral administration involves use of a slow release or sustained release system such that a constant dosage is maintained. See, e.g., U.S. Patent No. 3,610,795, which is incorporated by reference herein.

For solid compositions, conventional nontoxic solid carriers include, for example, pharmaceutical grades of mannitol, lactose, starch, magnesium stearate, sodium saccharin, talc, cellulose, glucose, sucrose, magnesium carbonate, and the like. Liquid pharmaceutically administrable compositions can, for example, be prepared by dissolving, dispersing, etc. an active compound as described herein and optional pharmaceutical adjuvants in an excipient, such as, for example, water, saline, aqueous dextrose, glycerol, ethanol, and the like, to thereby form a solution or suspension. If desired, the pharmaceutical composition to be administered may also contain minor amounts of nontoxic auxiliary substances such as wetting or emulsifying agents, pH buffering agents and the like, for example, sodium acetate, sorbitan monolaurate,

triethanolamine sodium acetate, triethanolamine oleate, etc. Actual methods of preparing such dosage forms are known, or will be apparent, to those skilled in this art; for example, see Remington's Pharmaceutical Sciences (Martin, E.W. (ed.), latest edition, Mack Publishing Co., Easton, PA).

In one embodiment, the TU of this invention can be administered to the subject by the use of electrotransfer mediated *in vivo* gene delivery, wherein immediately following administration of the TU to the subject, transcutaneous electric pulses are applied to the subject, providing greater efficiency and reproducibility of *in vivo* nucleic acid transfer to tissue in the subject (Mir et al., *Proc. Nat. Acad. Sci USA* 96: 4262-4267 (1999)).

In the methods of the present invention which describe the immunization of a subject by administering a vaccine of this invention to a subject, the efficacy of the immunization can be monitored according the clinical protocols well known in the art for monitoring the immune status of a subject.

An effective amount of a vaccinating composition is readily determined by those of skill in the art to be an amount which, when administered to a subject, confers protective immunity upon the subject. In order to undertake such a determination, the skilled artisan can assess the ability to induce flaviviral prM/M- and E-specific antibodies and/or flaviviral prM/M- and E-specific cytotoxic T lymphocytes present in the blood of a subject to whom the vaccine has been administered. One can also determine the level of protective immunity conferred upon an experimental subject by challenge with live flavivirus corresponding to the antigenic composition used to immunize the experimental subject. Such challenge experiments are well known to those of skill in the art.

In general, in order to immunize a subject against infection by WNV, JEV, YFV, dengue virus, SLEV, or other flaviviruses according to the present invention, and

recognizing that the TUs employed in such methods may have differing overall sizes, doses ranging from about 0.1 μg/kg body weight to about 50 μg/kg body weight can be used.

It has unexpectedly been found that a TU of the present invention which is a DNA confers protective immunity at a level of effectiveness approximating 100% after administration of only a single effective dose of the TU by i.m. injection or by electrotransfer. This is in contrast to many immunization methods carried out using conventional vaccines (as described above), which require one or more booster vaccinations and which may not confer protective immunity to an effectiveness near 100%.

It has further been found unexpectedly that protective immunity may be transmitted from a vaccinated female subject to the offspring of the subject. A significant proportion of neonatal mice was shown to be protected against viral challenge after the mothers were vaccinated using the TU DNA of the invention. Without wishing to be limited by theory, it is known that passive immunity may be conferred on neonatal mammals due to the presence in maternal milk of neutralizing antibodies specific for various pathogens. It is possible that the protective immunity against JEV found within the neonates was transmitted to them in this way.

In another embodiment of the invention, the TU encodes a signal sequence of a structural protein of a first flavivirus and an immunogenic flavivirus antigen of a second flavivirus. Thus, in one embodiment, for example, the signal sequence of structural protein of a first flavivirus is replaced by a signal sequence of structural protein of a second flavivirus, which results in proper folding of the nascent polypeptide, proper processing in a host, and/or proper folding of the processed protein. In another embodiment of the invention, the TU may encode an immunogenic flavivirus antigen wherein the antigen comprises sequence from one or more than one flavivirus.

The present invention further provides immunogenic compositions comprising the polypeptides of this invention in a pharmaceutical acceptable carrier for use as a protein vaccine. Antigens produced from the transcriptional units of the present invention can be used to elicit effective immune responses in a subject. Antigens for this purpose can comprise flavivirus prM protein, flavivirus M protein, flavivirus E protein or any combination thereof, including immunogenic fragments of the proteins. A particularly preferred embodiment is the use of the NRA described herein. A further preferred embodiment is a chimeric protein comprising the signal sequence of one flavivirus and the structural protein(s) of one or more different flaviviruses. In a particularly preferred embodiment, the signal sequence of the antigen is the Japanese encephalitis virus signal sequence.

In other embodiments, the protein vaccine of this invention further comprises a suitable adjuvant. As used herein, an "adjuvant" is a potentiator or enhancer of the immune response. The term "suitable " is meant to include any substance which can be used in combination with the vaccine immunogen (i.e., flavivirus prM protein, flavivirus M protein, flavivirus E protein, or any combination thereof) to augment the immune response, without producing adverse reactions in the vaccinated subject. Effective amounts of a specific adjuvant may be readily determined so as to optimize the potentiation effect of the adjuvant on the immune response of a vaccinated subject. In a preferred embodiment, adjuvanting of the vaccines of this invention is a 2 – stage process, utilizing first a 2% aluminum hydroxide solution and then a mineral oil. In specific embodiments, suitable adjuvants can be chosen from the following group: mineral, vegetable or fish oil with water emulsions, incomplete Freund's adjuvant, *E. coli* J5, dextran sulfate, iron oxide, sodium alginate, Bacto-Adjuvant, certain synthetic polymers such as Carbopol (BF Goodrich Company, Cleveland, Ohio), poly-amino acids and co-polymers of amino acids, saponin, carrageenan, REGRESSIN (Vetrepharm, Athens, GA), AVRIDINE (N, N-dioctadecyl-N',N'-bis(2-hydroxyethyl)-propanediamine), long chain polydispersed ß (1,4) linked mannan polymers interspersed with O-acetylated groups (e.g. ACEMANNAN), deproteinized highly

purified cell wall extracts derived from non-pathogenic strain of Mycobacterium species (e.g. EQUIMUNE, Vetrepharm Research Inc., Athens GA), Mannite monooleate, paraffin oil and muramyl dipeptide.

In another aspect, this invention provides a method for immunizing subjects with immunogenic amounts of the protein vaccine of the invention to elicit an effective immune response in the subject. Immunization can be carried out orally, parenterally, intranasally, intratracheally, intramuscularly, intramammarily, subcutaneously, intravenously and/or intradermally. The vaccine containing the flavivirus prM protein, flavivirus M protein and/or the flavivirus E protein can be administered by injection, by inhalation, by ingestion, or by infusion. A single dose can be given and/or repeated doses of the vaccine preparations, i.e. "boosters," can be administered at periodic time intervals to enhance the initial immune response or after a long period of time since the last dose. The time interval between vaccinations can vary, depending on the age and condition of the subject.

The term " immunogenic amount" means an amount of an immunogen, or a portion thereof, which is sufficient to induce an immune response in a vaccinated subject and which protects the subject against disease caused by wild-type or virulent flavivirus infections upon exposure thereto or which has a therapeutic or commercially beneficial effect that lessens the effect of flavivirus infection on the vaccinated subject.

The invention further provides an antibody produced in response to immunization by the antigen of this invention. The antibodies of the present invention can include polyclonal and monoclonal antibodies which can be intact immunoglobulin molecules, chimeric immunoglobulin molecules, "humanized antibodies," or Fab or $F(ab')_2$ fragments. Such antibodies and antibody fragments can be produced by techniques well known in the art which include those described in Harlow and Lane (Antibodies: A Laboratory Manual. Cold Spring Harbor Laboratory, Cold Spring Harbor, NY, 1989) and Kohler et al. (*Nature* 256:495-97, 1975) and U.S. Patents

5,545,806, 5,569,825 and 5,625,126, incorporated herein by reference. The antibodies can be of any isotype IgG, IgA, IgD, IgE and IgM.

The present invention can also include single chain antibodies (ScFv), comprising linked V_H and V_L domains and which retain the conformation and specific binding activity of the native idiotype of the antibody. Such single chain antibodies are well known in the art and can be produced by standard methods. (see, e.g., Alvarez et al., *Hum. Gene Ther.* 8: 229-242 (1997)).

Antibodies can be produced against the antigens of this invention which are synthesized from nucleic acid sequences encoding immunogenic amino acid sequences of the prM, M and/or E antigens of one or more flaviviruses and the signal sequence of a different flavivirus (e.g., JEV). Immunogenic peptides synthesized from the use of these chimeric constructs can easily be identified by use of methods well known in the art for identifying immunogenic regions in an amino acid sequence and used to produce the antibodies of this invention.

Conditions whereby an antigen/antibody complex can form, as well as assays for the detection of the formation of an antigen/antibody complex and quantitation of the detected protein, are standard in the art. Such assays can include, but are not limited to, Western blotting, immunoprecipitation, immunofluorescence, immunocytochemistry, immunohistochemistry, fluorescence activated cell sorting (FACS), fluorescence *in situ* hybridization (FISH), immunomagnetic assays, ELISA, ELISPOT (Coligan et al., eds. 1995. Current Protocols in Immunology. Wiley, New York.), agglutination assays, flocculation assays, cell panning, etc., as are well known to the artisan.

As used herein, the term "bind" means the well characterized binding of antibody to antigen as well as other nonrandom association with an antigen. "Specifically bind" as used herein describes an antibody or other ligand that does not

cross react substantially with any antigen other than the one specified, which in this case, is an antigen of this invention.

The antibody or ligand of this invention can be bound to a substrate (e.g., beads, tubes, slides, plates, nitrocellulose sheets, etc.) or conjugated with a detectable moiety or both bound and conjugated. The detectable moieties contemplated for the present invention can include, but are not limited to, an immunofluorescent moiety (e.g., fluorescein, rhodamine), a radioactive moiety (e.g., ^{32}P, ^{125}I, ^{35}S), an enzyme moiety (e.g., horseradish peroxidase, alkaline phosphatase), a colloidal gold moiety and a biotin moiety. Such conjugation techniques are standard in the art (for example, Harlow and Lane, Antibodies: A Laboratory Manual. Cold Spring Harbor Laboratory, Cold Spring Harbor, NY (1989); Yang et al., *Nature* 382: 319-324 (1996)).

The present invention further provides a method of detecting flavivirus antibody in a sample, comprising contacting the sample with the flavivirus antigen of the present invention, under conditions whereby an antigen/antibody complex can form; and detecting formation of the complex, thereby detecting flavivirus antibody in the sample.

The present invention further provides a method of detecting flavivirus antigen in a sample, comprising contacting the sample with an antibody of this invention under conditions whereby an antigen/antibody complex can form; and detecting formation of the complex, thereby detecting flavivirus antigen in the sample.

The method of detecting flavivirus antigen in a sample can be performed, for example, by contacting a fluid or tissue sample from a subject with an antibody of this invention and detecting binding of the antibody to the antigen. It is contemplated that the antigen will be on an intact flavivirus virion, will be a flavivirus-encoded protein displayed on the surface of a flavivirus-infected cell expressing the antigen, or will be a fragment of the antigen. A fluid sample of this method can comprise any biological fluid which could contain the antigen or a cell containing the antigen, such as

cerebrospinal fluid, blood, bile, plasma, serum, saliva and urine. Other possible examples of body fluids include sputum, mucus and the like.

The method of detecting flavivirus antibody in a sample can be performed, for example, by contacting a fluid or tissue sample from a subject with an antigen of this invention and detecting the binding of the antigen to the antibody. A fluid sample of this method can comprise any biological fluid which could contain the antibody, such as cerebrospinal fluid, blood, bile, plasma, serum, saliva and urine. Other possible examples of body fluids include sputum, mucus and the like.

Enzyme immunoassays such as immunofluorescence assays (IFA), enzyme linked immunosorbent assays (ELISA) and immunoblotting can be readily adapted to accomplish the detection of flavivirus antibodies according to the methods of this invention. An ELISA method effective for the detection of the antibodies can, for example, be as follows: (1) bind the antigen to a substrate; (2) contact the bound antigen with a fluid or tissue sample containing the antibody; (3) contact the above with a secondary antibody bound to a detectable moiety which is reactive with the bound antibody (e.g., horseradish peroxidase enzyme or alkaline phosphatase enzyme); (4) contact the above with the substrate for the enzyme; (5) contact the above with a color reagent; and (6) observe/measure color change or development.

Another immunologic technique that can be useful in the detection of flavivirus antibodies uses monoclonal antibodies (MAbs) for detection of antibodies specifically reactive with flavivirus antigens in a competitive inhibition assay. Briefly, sample is contacted with an antigen of this invention which is bound to a substrate (e.g., an ELISA 96-well plate). Excess sample is thoroughly washed away. A labeled (e.g., enzyme-linked, fluorescent, radioactive, etc.) monoclonal antibody is then contacted with any previously formed antigen-antibody complexes and the amount of monoclonal antibody binding is measured. The amount of inhibition of monoclonal antibody binding is measured relative to a control (no antibody), allowing for detection and

measurement of antibody in the sample. The degree of monoclonal antibody inhibition can be a very specific assay for detecting a particular flavivirus variety or strain, when based on monoclonal antibody binding specificity for a particular variety or strain of flavivirus. MAbs can also be used for direct detection of flavivirus antigens in cells by, for example, immunofluorescence assay (IFA) according to standard methods.

As a further example, a micro-agglutination test can be used to detect the presence of flavivirus antibodies in a sample. Briefly, latex beads, red blood cells or other agglutinable particles are coated with the antigen of this invention and mixed with a sample, such that antibodies in the sample that are specifically reactive with the antigen crosslink with the antigen, causing agglutination. The agglutinated antigen-antibody complexes form a precipitate, visible with the naked eye or measurable by spectrophotometer. In a modification of the above test, antibodies of this invention can be bound to the agglutinable particles and antigen in the sample thereby detected.

The present invention further provides a method of diagnosing a flavivirus infection in a subject, comprising contacting a sample from the subject with the antigen of this invention under conditions whereby an antigen/antibody complex can form; and detecting antigen/antibody complex formation, thereby diagnosing a flavivirus infection in a subject.

The present invention further provides a method of diagnosing a flavivirus infection in a subject, comprising contacting a sample from the subject with the antibody of this invention under conditions whereby an antigen/antibody complex can form; and detecting antigen/antibody complex formation, thereby diagnosing a flavivirus infection in a subject.

In the diagnostic methods taught herein, the antigen of this invention can be bound to a substrate and contacted with a fluid sample such as blood, serum, urine or saliva. This sample can be taken directly from the patient or in a partially purified

form. In this manner, antibodies specific for the antigen (the primary antibody) will specifically react with the bound antigen. Thereafter, a secondary antibody bound to, or labeled with, a detectable moiety can be added to enhance the detection of the primary antibody. Generally, the secondary antibody or other ligand, which is reactive, either specifically with a different epitope of the antigen or nonspecifically with the ligand or reacted antibody, will be selected for its ability to react with multiple sites on the primary antibody. Thus, for example, several molecules of the secondary antibody can react with each primary antibody, making the primary antibody more detectable.

The detectable moiety allows for visual detection of a precipitate or a color change, visual detection by microscopy, or automated detection by spectrometry, radiometric measurement or the like. Examples of detectable moieties include fluorescein and rhodamine (for fluorescence microscopy), horseradish peroxidase (for either light or electron microscopy and biochemical detection), biotin-streptavidin (for light or electron microscopy) and alkaline phosphatase (for biochemical detection by color change).

Particular embodiments of the present invention are set forth in the examples which follow. These examples are not intended to limit the scope of the invention as disclosed in this specification.

Examples

General methods utilizing molecular biology and recombinant DNA techniques related to preparing and expressing the nucleic acid TU molecules of the invention are set forth in, for example, Current Protocols in Molecular Biology, Ausubel et al., John Wiley and Sons, New York 1987 (updated quarterly), and Molecular Cloning: A Laboratory Manual 2nd Ed., Sambrook, Fritsch and Maniatis, Cold Spring Harbor Laboratory, Cold Spring Harbor, NY, 1989.

Example 1. Preparation of recombinant plasmids containing the transcriptional unit encoding JEV prM and E antigens. Genomic RNA was extracted from 150 μL of JEV strain SA 14 virus seed grown from mouse brain using a QIAamp™ Viral RNA Kit (Qiagen, Santa Clarita, CA). RNA, adsorbed on a silica membrane, was eluted in 80 μL of nuclease-free water, and used as a template for the amplification of JEV prM and E gene coding sequences. Primer sequences were obtained from the work of Nitayaphan et al. (*Virology* 177: 541-552 (1990)). A single cDNA fragment containing the genomic nucleotide region 389-2478 was amplified by the reverse transcriptase-polymerase chain reaction (RT-PCR). Restriction sites KpnI and XbaI, the consensus Kozak ribosomal binding sequence, and the translation initiation site were engineered at the 5' terminus of the cDNA by amplimer 14DV389 (nucleotide sequence, SEQ ID NO:1; amino acid sequence, SEQ ID NO:2). An in-frame translation termination codon, followed by a NotI restriction site, was introduced at the 3' terminus of the cDNA by amplimer c14DV2453 (SEQ ID NO:3) (Figure 2). One-tube RT-PCR was performed using a Titan RT-PCR Kit (Boehringer Mannheim, Indianapolis, IN). 10 μL of viral RNA was mixed with 1 μL each of 14DV389 (50 μM) and c14DV2453 (50 μM) and 18 μL of nuclease-free water and the mixture was heated at 85°C for 5 min and then cooled to 4°C. 75 μL of reaction mix [20 μL 5x buffer, 2 μL of dNTP mixture (10 mM each), 5 μL of dithiothreitol (0.1 mM), 0.5 μL of RNasin™ (40 U/μL, Boehringer Mannheim), 2 μL of polymerase mixture, and 45.5 μL of nuclease-free water] was added and RT-PCR performed as follows: 1 cycle (50°C for 30 min, 94°C for 3 min, 50°C for 30 s, 68°C for 2.5 min), 9 cycles (94°C for 30 s, 50°C for 30 s, 68°C for 2.5 min), 20 cycles (94°C for 30 s, 50°C for 30 s, 68°C for 2.5 min in the first cycle, with an increment of 5 s per cycle thereafter), and a final extension at 68°C for 15 min. The RT-PCR product was purified by a QIAquick™ PCR Purification Kit (Qiagen) and eluted with 50 μL of 1 mM Tris-HCl, pH 7.5.

All vector constructions and analyses were carried out by using standard techniques (Sambrook et al., 1989). RT-PCR amplified cDNA, digested with KpnI and NotI nucleases, was inserted into the KpnI-NotI site of eukaryotic expression plasmid

vector (pCDNA3, Invitrogen, Carlsbad, CA). Electroporation-competent *Escherichia coli* XL1-Blue cells (Stratagene, La Jolla, CA) were transformed by electroporation (Gene Pulser™, Bio-Rad, Hercules, CA) and plated onto LB agar plates containing 100 μg/mL carbenicillin (Sigma Chemical Co., St. Louis, MO). Clones were picked and inoculated into 3 mL LB broth containing 100 μg/mL carbenicillin. Plasmid DNA was extracted from a 14 h culture using a QIAprep™ Spin Miniprep Kit (Qiagen). Automated DNA sequencing was performed as recommended (Applied Biosystems/Perkin Elmer, Foster City, CA). Both strands of the cDNA were sequenced and shown to be identical to the sequence for the original SA14 strain (Nitayaphan et al., 1990).

The fragment of plasmid pCDNA3 (Invitrogen, Carlsbad, CA) from nucleotide (nt) 1289 to nt 3455, containing fl ori, SV40 ori, the neomycin resistance gene, and SV40 poly(A) elements was deleted by PvuII digestion and then ligated to generate the pCBamp plasmid. The vector pCIBamp, containing a chimeric intron insertion at the NcoI/KpnI site of the pCBamp was constructed by excising the intron sequence from pCI (Promega, Madison, WI) by digestion with NcoI and KpnI. The resulting 566-bp fragment was cloned into pCBamp by digesting with NcoI-KpnI to replace its 289-bp fragment. Figure 3 presents the relationships between the plasmids pCDA3, pCBamp, and pCIBamp.

Plasmids containing the transcriptional unit encoding JEV prM and E proteins were prepared from these plasmids. The cDNA fragment containing the JEV prM and E coding regions in the recombinant plasmid pCDJE2-7 (nucleotide sequence, SEQ ID NO:10; amino acid sequence, SEQ ID NO:11), derived from the pCDNA3 vector, was excised by digestion with NotI and KpnI or XbaI and cloned into the KpnI-NotI site of pCBamp, pCIBamp, pCEP4 (Invitrogen, Carlsbad, CA), or pREP4 (Invitrogen, Carlsbad, CA), or into the SpeI-NotI site of pRc/RSV (Invitrogen, Carlsbad, CA) expression vector to create pCBJE1-14 (nucleotide sequence, SEQ ID NO:17; amino acid sequence, SEQ ID NO:18), pCIBJES14, pCEJE, pREFE, and pRCJE, respectively.

Both strands of the cDNA from clones of each plasmid were sequenced and recombinant clones with the correct nucleotide sequence were identified. Plasmid DNA for use in the in vitro transformation of mammalian cells or mouse immunization experiments was purified by anion exchange chromatography using an EndoFree™ Plasmid Maxi Kit (Qiagen).

<u>Example 2. Evaluation of JEV prM and E proteins expressed by various recombinant plasmids using an indirect immunofluorescent antibody assay</u>. The expression of JEV specific gene products by the various recombinant expression plasmids was evaluated in transiently transfected cell lines of COS-1, COS-7 and SV-T2 (ATCC, Rockville MD; 1650-CRL, 1651-CRL, and 163.1-CCL, respectively) by indirect immunofluorescent antibody assay (IFA). The SV-T2 cell line was excluded from further testing since a preliminary result showed only 1-2% of transformed SV-T2 cells were JEV antigen positive. For transformation, cells were grown to 75% confluence in 150 cm^2 culture flasks, trypsinized, and resuspended at 4°C in phosphate buffered saline (PBS) to a final cell count 5 x 10^6 per mL. 10 μg of plasmid DNA was electroporated into 300 μL of cell suspension using a BioRad Gene Pulse™ (Bio-Rad) set at 150 V, 960 μF and 100 Ω resistance. Five minutes after electroporation, cells were diluted with 25 mL fresh medium and seeded into a 75 cm^2 flask. 48 h after transformation the medium was removed from the cells, and the cells were trypsinized and resuspended in 5 mL PBS with 3% normal goat serum. 10 μL aliquots were spotted onto slides, air dried and fixed with acetone at -20°C for 20 min. IFA was performed with acetone-fixed plasmid-transformed cells using fluorescein isothiocyanate-conjugated goat anti-mouse immunoglobulin G (Sigma Chemical Co.) and JEV HIAF.

To determine the influence of various promoter and poly(A) elements on the JEV prM and E protein expression, COS-1 and COS-7 cell lines were transiently transformed by an equal amount of pCDJE2-7 (SEQ ID NO:10), pCEJE, pREJE, or pRCJE plasmid DNA. JEV antigens were expressed in both cell lines transformed by

all four recombinant plasmids, thus confirming that the CMV or RSV (rous sarcoma virus) promoter and BGH or SV40 poly(A) elements were functionally active. However, the percentage of transformed cells and the level of JEV antigens expressed, as determined by the number of IFA positive cells and IFA intensity, respectively, differed greatly among the various plasmids (Table 1). A significantly high percentage of COS-1 cells transformed by pCDJE2-7 (SEQ ID NO:10), pCBJE1-14 (SEQ ID NO:17) and pCIBJES14 expressed the JEV antigens, and the level of the expressed proteins was compatible with JEV-infected cells. Cells transfected with pCEJE, pREJE, or pRCJE vectors, on the other hand, had a low percentage of antigen-expressing cells, as well as a low intensity of fluorescence, indicating weak expression of the antigens.

In order to ascertain whether the enhanced expression of JEV proteins by pCDJE2-7 (SEQ ID NO:10) was influenced by the SV40-encoded eukaryotic origin of replication, the plasmid pCBJE1-14 (SEQ ID NO:17) was constructed so that a 2166-bp fragment, containing f1 ori, SV40 ori, the neomycin resistance gene and SV40 poly(a) elements from pCDJE2-7, was deleted. A chimeric intron was then inserted into pCBJE1-14 to generate pCIBJES14. The pCIBJES14 plasmid was used to determine if the expression of JEV proteins could be enhanced by the intron sequence. Following transformation, cells harboring both pCBJE1-14 and pCIBJES14 vectors expressed a level of JEV antigens similar to that observed with pCDJE2-7 (Table 1). This result indicates that expression of JEV prM and E antigens by recombinant vectors is influenced only by the transcriptional regulatory elements. Neither the eukaryotic origin of replication nor the intron sequence enhanced JEV antigen expression in the cells used. Vectors containing the CMV promoter and BGH poly(A) (Figure 3) were selected for further analysis.

<u>Example 3. Selection of an in vitro transformed, stable cell line constitutively expressing JEV specific gene products</u>. COS-1 cells were transformed with 10 μg of pCDJE2-7 DNA by electroporation as described in the previous example. After a 24 hr

incubation in non-selective culture medium, cells were treated with neomycin (0.5 mg/mL, Sigma Chemical Co.). Neomycin-resistant colonies, which became visible after 2-3 weeks, were cloned by limited dilution in neomycin-containing medium. Expression of vector-encoded JEV gene products was initially screened by IFA using JEV HIAF. One JEV-IFA positive clone (JE-4B) and one negative clone (JE-5A) were selected for further analysis and maintained in medium containing 200 μg/mL neomycin.

Authenticity of the JEV E protein expressed by the JE-4B clone was demonstrated by epitope mapping by IFA using a panel of JEV E-specific murine monoclonal antibodies (Mab) (Kimura-Kuroda et al., *J. Virol.* 45: 124-132 (1983); Kimura-Kuroda et al., *J. Gen. Virol.* 67: 2663-2672 (1986); Zhang et al., *J. Med. Virol.* 29: 133-138 (1989); and Roehrig et al., *Virol.* 128: 118-126 (1983)). JEV HIAF and normal mouse serum were used as positive and negative antibody controls, respectively. Four JEV-specific, six flavivirus-subgroup specific, and two flavivirus-group reactive Mabs reacted similarly with the 4B clone or JEV-infected COS-1 cells (Table 2).

<u>Example 4. Antigenic properties and immunological detection of subviral particles secreted by the JE-4B COS-1 cell line</u>.

<u>a. Preparation of subviral particles.</u> JE-4B COS-1 cells were grown and maintained in medium containing 200 μg/mL of neomycin. The cultured medium was routinely harvested and stored at 4°C, and replenished twice weekly, and the cells were split 1:5 every 7-10 days. Culture medium was clarified by centrifugation at 10,000 rpm for 30 min in a Sorvall F16/250 rotor at 4°C, and centrifuged further for 4 hr at 39,000 rpm in a Sorvall TH641 rotor at 4°C through a 5% sucrose cushion (w/w, prepared with 10 mM Tris HCl, pH 7.5, 100 mM NaCl (TN buffer)). The pellet containing subviral particles was resuspended in TN buffer and stored at 4°C. Alternatively, 7% or 10% PEG-8000 (w/v) was added to the clarified culture medium. The mixture was stirred at 4°C for at least 2 hr, and the precipitated particles were

collected by centrifugation at 10,000 rpm for 30 min. The precipitate was resuspended in TN buffer and stored at 4°C. The subviral particles were purified from both pelleted and PEG-precipitated preparations by rate zonal centrifugation in a 5-25% continuous sucrose gradient in TN at 38,000 rpm at 4°C for 90 min. 1-mL fractions were collected from the top of the gradient, tested by antigen capture ELISA (see below), and the positive fractions loaded onto a 25-50% sucrose gradient in TN. This was centrifuged overnight in an equilibrium density centrifugation at 35,000 rpm at 4°C. 0.9-mL fractions from the equilibrium gradients were collected from the bottom. They were tested by antigen-capture ELISA and assessed for hemagglutination (HA) activity at pH 6.6. An aliquot of 100 μL of each fraction was weighed precisely to determine its density. The ELISA-positive fractions were pooled and pelleted at 39,000 rpm at 4°C for 3-4 hr and the pellet resuspended in TN buffer. Antigen-capture ELISA and HA titers were determined on the pelleted samples. JEV-infected COS-1 cell supernatant was also subjected to similar purification protocols as detailed above and used as a positive control for the gradient analysis. JE virions were also purified from infected C6/36 cells 5-6 days postinfection by sedimentation in a glycerol/tartrate equilibrium gradient.

<u>b. Western blots of subviral particles.</u> Gradient-purified samples of the subviral particles were mixed with electrophoresis sample buffer and run on 10 or 12.5% sodium dodecyl sulfate-containing polyacrylamide gels (SDS-PAGE) as described by Laemmli (*Nature* 277: 680-685 (1970)). Proteins were transferred to a nitrocellulose membrane and immunochemically detected with polyclonal JEV HIAF, flavivirus cross-reactive anti-E Mab 4G2 (Henchal et al., *Amer. J. Trop. Med. Hyg.* 31: 830-836 (1982)), or mouse anti-prM peptide hyperimmune serum (JM01). Figure 4 shows a comparison of the M and E proteins produced by JEV infected C6/36 and JE-4B COS-1 cells. Some nonspecific reactivity to E protein was observed in the normal mouse ascitic fluid and Jmo1 anti-peptide serum. Proteins identical in size to M and E were secreted in the subviral particles and could be detected by E-specific Mab 4G2 and prM-specific JM01 antiserum, respectively.

<u>c. Density gradient detection of JEV subviral particles in culture medium.</u> For ELISA, antigen-capture antibody (4G2) was diluted in 0.1 M sodium carbonate buffer, pH 9.6, and used to coat 96-well microtiter plates (Immulon II, Dynatech. Chantilly, VA) by overnight incubation at 4° C. After blocking with 3% normal goat serum in PBS, two-fold serially-diluted samples were added to the 4G2-coated plate and incubated 1.5 hours at 37°C. Captured antigen was detected by horseradish peroxidase-conjugated 6B6C-1 Mag, and incubated for 1 hour at 37°C. The enzyme activity on the solid phase was then detected with TMB (3,3',5,5'-tetramethylbenzidine)-ELISA (Life Technologies, Grand Island, NY).

Approximately 500 mL of cell culture medium from 15 X 150 cm^2 flasks of JE-4B cells was collected four days after cells were seeded. PEG-precipitated subviral particles were resuspended in 2 mL of TN buffer, pH 7.5; a 0.7 mL aliquot of this resuspended pellet was loaded onto a 5-25% sucrose gradient. Triton X-100, which disrupts subviral particles, was added to another 0.7 mL aliquot to a final concentration of 0.1% and this was loaded onto a 5-25% sucrose gradient prepared in TN buffer containing 0.1% Triton X-100. A definite opaque band was observed approximately 2.5 cm from the top of the gradient containing Triton X-100, but not in the gradient without detergent. Fractions (1 mL) were collected from top to bottom for each gradient (Figure 5). Each collected fraction was analyzed by antigen capture ELISA. Antigen was detected in fractions 4-6, indicating relatively rapid sedimentation characteristic of subviral particles. Treatment of the PEG precipitate from JE-4B culture medium with Triton X-100 shifted the position of ELISA-reactive material to the top of the gradient. Thus treatment with Triton X-100 produces only slow-sedimenting molecules. A similar finding was reported by Konishi et al. (*Virol.* 188: 714-720 (1992)). These results show that rapidly sedimenting subviral particles containing prM/M and E could be disrupted by detergent treatment.

Hemagglutination (HA) activity was determined in the pH range from 6.1 to 7.0 by the method of Clarke and Casals (*Amer. J. Trop. Med. Hyg.* 7: 561-573 (1958)).

The subviral particle secreted by JE-4B cells and the virion particle produced by JEV infected COS-1 cells had a similar HA profile with the optimum pH determined to be 6.6.

Example 5. Comparison of the immune response in mice vaccinated with pCDJE2-7 nucleic acid vaccine of the invention and commercial JEV vaccine. Groups of five 3-week-old female, ICR outbred mice were injected intramuscularly in the left and right quadriceps with 100 μg of pCDJE2-7 plasmid in 100 μL of dH_2O or were given doses of JE-VAX (manufactured by the Research Foundation for Microbial Disease of Osaka University and distributed by Connaught Laboratories, Swiftwater, PA.) subcutaneously that are one-fifth the dose given to humans. The plasmid pCDNA3/CAT (Invitrogen), which encodes and expresses an unrelated protein, was used as the negative vaccination control. Except for one group of pCDJE2-7-vaccinated mice, all animals were boosted 3 weeks later with an additional dose of plasmid or JE-VAX. Mice were bled from the retroorbital sinus at 3, 6, 9, 23, 40 and 60 weeks after inoculation. JEV antibody titers were determined by enzyme-linked imunosorbent assay (ELISA) against purified JEV or by plaque reduction neutralization tests (PRNT) (Roehrig et al., *Virol.* 171: 49-60 (1989); and Hunt and Calisher, *Amer. J. Trop. Med. Hyg.* 28: 740-749 (1979)).

The pCDJE2-7 nucleic acid vaccine and JE-VAX provided 100% seroconversion within three weeks after the first vaccination in all three groups of mice (Table 3). The JEV ELISA and PRNT antibody titers reached the highest level at week 6 and week 9, respectively, after immunization. Mice receiving 1 dose of DNA vaccine had similar antibody responses as those receiving 2 doses. Comparable ELISA antibody titers were maintained in DNA-vaccinated groups up to 60 weeks, after which the experiment was terminated. However, only one of four mice in the JE-VAX group was JEV antibody positive at 60 weeks post-inoculation. The pCDNA3/CAT control group did not have any measurable JEV antibody. These results demonstrate that a

single dose of JEV-specific nucleic acid vaccine is more effective in maintaining JEV antibody in mice than the commercial, FDA-approved JE-VAX vaccine.

Example 6. Comparison of various nucleic acid vaccine constructs of the invention and commercial JEV vaccine for effectiveness of vaccination at different ages. A similar level of JEV protein was expressed by COS-1 cells transformed by either pCDJE2-7, pCBJE1-14, or pCIBJES14. JEV antibody induction by these nucleic acid constructs was compared to JE-VAX commercial vaccine at two different ages at vaccination. Three-day (mixed sex) or 3-week-old (female) ICR outbred mice, 10 per group, were vaccinated intramuscularly with 50 or 100 μg of plasmid DNA, or subcutaneously with doses of JE-VAX that are one-tenth or one-fifth the dose given to humans. Serum specimens were collected at 3 and 7 weeks after immunization and tested at a 1:1600 dilution by ELISA using purified JEV as an antigen. Results are shown in Table 4.

Plasmid pCBJE1-14 provided the highest extent of seroconversion, i.e., antibody titer greater than 1:1600, achieving 80-100% at both ages of vaccination. Administration of pCDJE2-7 or pCIBJES14 provided moderate seroconversion by 7 weeks when 3-day old mice were vaccinated (60% for each), but weaker seroconversion (40% and 10%, respectively) when measured 3 weeks after vaccination. When these plasmids were administered at the age of 3 weeks, however, seroconversions of 90% or 100% were attained at both 3 weeks and 7 weeks after vaccination. In contrast, the commercial vaccine, JE-VAX, conferred no seroconversion when administered at 3 days of age, and 100% when given at 3 weeks of age. Thus the nucleic acid TU's for JEV prM and E provided an extent of seroconversion better than a very high dose of the commercial vaccine, and unexpectedly high seroconversion in both young and more mature animals.

Example 7. Protective immunity conferred by the nucleic acid vaccine of the invention. Three-day old vaccinated groups from Example 6 were challenged 7 weeks

after vaccination by intraperitoneal injection of 50,000 pfu/100 μL of the mouse-adapted JEV strain SA14 and observed for 3 weeks. 100% protection was achieved in groups that received various nucleic acid TU-containing vaccine constructs for up to 21 days (Table 5). In contrast, 60% of the JE-VAX-vaccinated mice, as well as 70% of the pCDNA3/CAT-vaccinated negative controls, did not survive virus challenge by 21 days. These results indicate that the nucleic acid TU's of the invention confer unexpectedly effective protection on vaccinated mice. This suggests the possibility of employing the nucleic acid vaccine of the invention as an early childhood vaccine for humans. In contrast, JE-VAX, the inactivated human vaccine currently used, does not appear to be effective in young animals.

<u>Example 8. Passive protection of neonatal mice correlated with the maternal antibody titer</u>. Female ICR mice at the age of 3 weeks were vaccinated with either one dose or two doses spaced two days apart of pCDJE2-7 plasmid DNA, at 100 μg/100 μL, or with two doses of JE-VAX that were one-fifth the dose given to humans. The negative control group received two doses of 100 μg/100 μL of pCDNA-3/CAT plasmid. Passive protection by maternal antibody was evaluated in pups resulting from matings of experimental females with non-immunized male mice that occurred nine weeks following the first vaccination or 6 weeks following the second vaccination. Pups were challenged between 3-15 days after birth by intraperitoneal administration of 5,000 pfu/100 μL of mouse-adapted SA14 virus and observed daily for 3 weeks (Table 6). The survival rates correlated with the maternal neutralizing antibody titers. 100% of pups nursed by mothers with a PRNT of 1:80 survived viral infection, whereas none of the pups from the control mother survived (Table 6). Partial protection of 45% and 75% was observed in older pups that were nursed by mothers with a PRNT titer of 1:20 and 1:40, respectively. The survival rates also correlated with the length of time that pups were nursed by the immune mother. As just indicated, 13-15 day old pups had high survival rates. None of the 3-4 day old pups, however, survived virus challenge when the mother had a PRNT titer of 1:20 or 1:40. Thus maternal antibody provides

partial to complete protective immunity to the offspring. In addition, JEV antibody was detected by ELISA in the sera of 97% (29/30) of the post-challenge pups.

Mice were inoculated intramuscularly with 1 or 2, 100 μg doses of plasmid DNA, or subcutaneously with two, 1/5 human doses of JE-VAX vaccine. Sera were collected 9 weeks post-vaccination for PRNT testing prior to mating with non-immune male.

Example 9. Preparation of recombinant plasmids containing the transcriptional unit encoding WNV prM and E antigens. Genomic RNA was extracted from 150 μL of Vero cell culture medium infected with NY 99-6480 strain, an strain isolated from the outbreak in New York 1999, using the QIAamp ™ Viral RNA Kit (Qiagen, Santa Clarita, CA). Extracted RNA was eluted and suspended in 80 μl of nuclease-free water, and used as a template for the amplification of WNV prM and E gene coding sequences. Primer sequences were obtained from the work of Lanciotti et al. (*Science* 286: 2333-2337 (1999)). A cDNA fragment containing the genomic nucleotide region was amplified by the reverse transcriptase-polymerase chain reaction (RT-PCR). Restriction sites BsmBI and KasI were engineered at the 5' terminus of the cDNA by using amplimer WN466 (nucleotide sequence, SEQ ID NO:12). An in-frame translation termination codon , followed by a NotI restriction site was introduced at the 3' terminus of the cDNA by using amplimer cWN2444 (SEQ ID NO:13). The RT-PCR product was purified by a QIAquick™ PCR Purification Kit (Qiagen).

The double-stranded amplicon produced by use of the two amplimers above (SEQ ID NO:12 and SEQ ID NO:13) was digested with KasI and NotI enzymes to generate a 998 bp (nt-1470 to 2468) fragment of DNA was inserted into the KasI and NotI sites of a pCBJESS vector to form an intermediate plasmid, pCBINT. The pCBJESS was derived from the pCBamp plasmid, that contained the cytomegalovirus early gene promoter and translational control element and an engineered JE signal

sequence element (Chang et al., *J. Virol.* 74: 4244-4252 (2000)). The JE signal sequence element comprises the JE signal sequence (SEQ ID NO:14).

The cDNA amplicon was subsequently digested with BsmBI and Kas I enzymes and the remaining 1003 bp fragment (nt-466 to 1470) was inserted in to the KasI site of pCBINT to form pCBWN (nucleic acid sequence, SEQ ID NO:15; amino acid sequence, SEQ ID NO:16). Automated DNA sequencing using an ABI prism 377 Sequencer (Applied Biosystems/Perkin Elmer, Foster City, CA) was used to confirm that the recombinant plasmid had a correct prM and E sequence as defined by Lanciotti et al. (*Science* 286: 2333-2337 (1999)).

Plasmid DNA for use in the in vitro transformation of mammalian cells or mouse immunization experiments was purified by anion exchange chromatography as described in Example 1.

<u>Example 10. Immunochemical characterization and evaluation of WNV prM and E proteins expressed by pCBWN</u>. WNV specific gene products encoded by the pCBWN plasmid were expressed in COS-1 cells. Cells were electroporated and transformed with pCBWN plasmid according to Chang et al. (*J. Virol.* 74: 4244-4252 (2000)). Electroporated cells were seeded onto 75 cm^2 culture flasks or a 12-well tissue culture dish containing one sterile coverslip/well. All flasks and 12-well plates were kept at 37°C, 5% CO_2 incubator. Forty hours following electroporation, coverslips containing adherent cells were removed from the wells, washed briefly with PBS, fixed with acetone for 2 minutes at room temperature, and allowed to air dry.

Protein expression was detected using indirect immunofluorescence antibody assay (IFA), as described in Example 2. Flavivirus E-protein specific monoclonal antibody (Mab) 4G2, WNV mouse hyperimmune ascitic fluid (HIAF) and normal mouse serum (NMS) at 1:200 dilution in PBS were used as the primary antibody to detect protein expression (Henchal et al., *Am. J. Trop. Med. Hyg.* 31: 830-836 (1982)).

Tissue culture medium was harvested 40 and 80 hours following electroporation. Antigen-capture (Ag-capture) ELISA was used to detect secreted WN virus antigen in the culture medium of transiently transformed COS-1 cells. The Mab 4G2 and horseradish peroxidase-conjugated Mab 6B6C-1 were used to capture the WN virus antigens and detect captured antigen, respectively (Chang et al., *J. Virol.* 74: 4244-4452 (2000); Henchal et al., *Am. J. Trop. Med. Hyg.* 31: 830-836 (1983); Roehrig et al., *Virology* 128: 118-126 (1983)).

WN virus antigen in the medium was concentrated by precipitation with 10 % polyethylene glycol (PEG)-8000. The precipitant was resuspended in TNE buffer (50 mM Tris, 100 mM NaCl, 10 mM EDTA, pH 7.5), clarified by centrifugation, and stored at 4°C. Alternatively, the precipitant was resuspended in a lyophilization buffer (0.1 M TRIZMA and 0.4% bovine serum albumin in borate saline buffer, pH 9.0), lyophilized and stored at 4°C. Lyophilized preparations were used as antigen for the evaluation in MAC- and indirect IgG ELISAs.

WN virus-specific protein was detected by IFA on the transiently transformed COS-1 cells. E, prM and M proteins expressed in these cells were secreted into the culture medium. WN virus antigen concentrated by PEG precipitation was extracted with 7.0 % ethanol to remove residual PEG (Aizawa et al., *Appl. Enviro. Micro.* 39: 54-57 (1980)). Ethanol extracted antigens and gradient-purified WN virions were analyzed on a NuPAGE, 4-12% gradient Bis-Tris Gel in a Excel Plus Electrophoresis Apparatus (Invitrogen Corp., Carlsbad,CA) and followed by electroblotting onto nitrocellulose membranes using a Excel Plus Blot Unit (Invitrogen Corp.). WN virus-specific proteins produced by the transiently transformed COS-1 cells were detected by WN virus specific mouse HIAF or flavivirus E protein reactive Mab 4G2 in a Western blot analysis, using NMS as a negative serum control. The proteins displayed similar reactivity and identical molecular weights to the corresponding gradient purified virion E, prM and M protein derived from WN virus infected suckling mouse brain (SMB).

In analysis of the NRA as an antigen for diagnostic ELISA, one vial of lyophilized NRA, representing antigen harvested from 40 ml of tissue culture fluid, was reconstituted in 1.0 ml of distilled water and compared with the reconstituted WN virus infected suckling mouse brain (SMB) antigen provided as lyophilized as β-propiolactone-inactivated sucrose-acetone extracts (Clarke et al., *Am. J. Trop. Med. Hyg.* 7: 561-573 (1958)). All recombinant proteins, prM, M and E , had a similar reactivity to that of the gradient-purified virion E, prM and M proteins.

Coded human specimens were tested concurrently with antigens in the same test at the developmental stage. The MAC- and IgG ELISA protocols employed were identical to the published methods (Johnson et al., *J. Clin. Microbiol.* 38: 1827-1831 (2000); Martin et al., *J. Clin. Microbiol.* 38: 1823-1826. (2000)). Human serum specimens were obtained from the serum bank in our facility, which consists of specimens sent to the DVBID for WN virus confirmation testing during the 1999 outbreak In these tests, a screening MAC- and IgG ELISA were performed on a 1:400 specimen dilution. Specimens yielding positive/negative (P/N) OD ratios between 2 and 3 were considered suspect positives. Suspect serum specimens were subject to confirmation as positives by both ELISA end-point titration and plaque-reduction neutralization test (PRNT). All specimens yielding P/N OD ratios greater than 3.0 were considered positives without further confirmatory testing.

An Ag-capture ELISA employing flavivirus-group reactive, anti-E Mab, 4G2 and 6B6C-1, was used to detect NRA secreted into culture fluid of pCBWN transformed COS-1 cells. The antigen could be detected in the medium one day following transformation; and the maximum ELISA titer (1:32-1:64) in the culture fluid without further concentration was observed between day two and day four. NRA was concentrated by PEG precipitation, resuspended in a lyophilization buffer, and lyophilized for preservation. For diagnostic test development, one vial of lyophilized NRA was reconstituted with 1.0 ml distilled water and titrated in the MAC- or indirect IgG ELISA using WN virus positive and negative reference human sera (Johnson et al.,

J. Clin. Microbiol. 38: 1827-1831 (2000); Martin et al., *J. Clin. Microbiol.* 38: 1823-1826 (2000)). Dilutions 1:320 and 1:160 of the NRA were found to be the optimal concentrations for use in MAC- and IgG ELISA, respectively. These dilutions resulted in a P/N OD_{450} ratio of 4.19 and 4.54, respectively, for MAC- and IgG test. The WN virus SMB antigens produced by NY-6480 and Eg101 strains were used at 1:320 and 1:640 dilution for MAC-ELISA, and 1:120 and 1:320 for IgG ELISA, respectively. The negative control antigens, PEG precipitates of the culture medium of normal COS-1 cells and normal SMB antigen, were used at the same dilutions as for the respective NRA and SMB antigen. Human serum specimens, diluted at 1:400, were tested concurrently in triplicate with virus-specific and negative control antigens. For the positive test result to be valid, the OD_{450} for the test serum reacted with viral antigen (P) had to be at least two-fold greater than the corresponding optical density value of the same serum reacted with negative control antigen (N).

The reactivity of NRA and NY-06480, Eg101 and SLE virus SMBs were compared by the MAC- and IgG ELISAs using 21 coded human serum specimens. Of the 21 specimens, 19 had similar results on all three antigens (8 negatives and 11 suspect positives or positives). Eighteen specimens were also tested separately using SLE SMB antigen. Only three of 13 Eg-101-SMB positive specimens were positive in the SLE MAC-ELISA (Table 1). None of WN antigen negative specimens was positive by SLE MAC-ELISA. This result confirmed a previous observation that anti-WN virus IgM did not cross-react significantly with other flaviviruses (Tardei et al., *J. Clin. Microbiol.* 38: 2232-2239 (1940)) and was specific to diagnose acute WN virus infection regardless of whether NRA or SMB antigen was used in the test. All of the specimens were also tested concurrently by indirect IgG ELISA. Ten of 21 specimens were positive using any of the three antigens.

The two discrepant serum specimens (7 and 9) both from the same patient, collected on day-4 and 44 after onset of disease, respectively, were IgM-negative with NRA and SMB NY antigen and IgM-positive using Eg-101 SMB antigen in the initial

test. To investigate these two discordant specimens further, six sequentially collected specimens from this patient were retested by end-point MAC- and IgG ELISAs. A greater than 32-fold serial increase shown in the MAC-ELISA titer between day-3 and day-15 could be demonstrated with all antigens used. Cerebrospinal fluid collected on day-9 after onset of disease also confirmed that this patient indeed was infected by WN shortly prior to taking the sample. The cerebrospinal fluid had IgM P/N reading of 13.71 and 2.04 against Eg-101- and SLE-SMB antigens, respectively. Day-31 and day-44 specimens were negative (<1:400) by using NY-SMB antigen but positive by using NRA and Eg101-SMB. Compatible IgG titers were observed with all three antigen used in the test.

<u>Example 11. Evaluation of the immune response in animals vaccinated with pCBWN</u>. Groups of ten, three-wk-old female ICR mice were used in the study. Mice were injected intramuscularly (i.m.) with a single dose of pCBWN or a green fluorescent protein expressing plasmid (pEGFP) DNA (Clonetech, San Francisco, CA.). The pCBWN plasmid DNA was purified from XL-1 blue cells with EndoFree Plasmid Giga Kits (Qiagen) and resuspended in PBS, pH 7.5, at a concentration of 1.0 μg/μl. Mice that received 100 μg of pEGFP were used as unvaccinated controls. Mice were injected with the pCBWN plasmid at a dose of 100, 10, 1.0, or 0.1 μg in a volume of 100 μl. Groups that received 10, 1.0, or 0.1 μg of pCBWN were vaccinated by the electrotransfer mediated *in vivo* gene delivery protocol using the EMC-830 square wave electroporator (Genetronics Inc. San Diego, CA.). The electrotransfer protocol was based on the method of Mir et al., (*Proc. Natl. Acad. Sci. USA* 96: 4262-4267.(1999)). Immediately following DNA injection, transcutaneous electric pulses were applied by two stainless steel plate electrodes, placed 4.5-5.5 mm apart, at each side of the leg. Electrical contact with the leg skin was ensured by completely wetting the leg with PBS. Two sets of four pulses of 40 volts/mm of 25 msec duration with a 200 msec interval between pulses were applied. The polarity of the electrode was reversed between the set of pulses to enhance electrotransfer efficiency.

Mice were bled every 3 wks following injection. The WN virus specific antibody response was evaluated by Ag-capture ELISA and plaque reduction neutralization test (PRNT). Individual sera were tested by IgG-ELISA, and pooled sera from 10 mice of each group were assayed by PRNT. All the mice vaccinated with pCBWN had IgG ELISA titers ranging from 1:640 to 1:1280 three wks after vaccination. The pooled sera collected at three and six wks had a Nt antibody titer of 1:80. None of the serum specimens from pEGFP control mice displayed any ELISA or Nt titer to WN virus.

To determine if the single i.m. vaccination of pCBWN could protect mice from WN virus infection, mice were challenged with NY-6480 virus either by intraperitoneal injection or by exposure to the bite of virus-infected *Culex* mosquitoes. Half of the mouse groups were challenged intraperitoneally (ip) at 6 wks post vaccination with 1,000 LD_{50} (1,025 PFU/100 μl) of NY99-6480 virus. The remaining mice were each exposed to the bites of three Culex tritaeniorhynchus mosquitoes that has been infected with NY99-6480 virus 7 days prior to the challenge experiment. Mosquitoes were allowed to feed on mice until they were fully engorged. Mice were observed twice daily for three wks after challenge.

It was evident that the presence of Nt antibodies correlated with protective immunity, since all mice immunized with WN virus DNA remained healthy after virus challenge while all control mice developed symptoms of CNS infection 4-6 days following virus challenge and died on an average of 6.9 and 7.4 days after intraperitoneal or infective mosquito challenge, respectively. In the vaccinated group, the pooled sera collected three wks after virus challenge (9-wk post immunization) had Nt antibody titers of 1:640 or 1:320. Pooled vaccinated mouse sera reacted only with E protein in the Western blot analysis.

Groups of ten mice were immunized with 10.0 to 0.1 μg of pCBWN per animal by use of electrotransfer. All groups that received pCBWN were completely protected

from virus challenge. At 6 wks after immunization all groups of electrotransfer mice had Nt titer less than four-fold different than animals receiving 100 µg of pCBWN by conventional i.m. injection without electrotransfer. Both these results evidencing effective immunization suggest that the electrotransfer protocol enhances the immunogenicity and protective efficacy of the DNA vaccine of the invention (when carried out as described in (Mir et al., *Proc. Natl. Acad. Sci. USA.* 96: 4262-4267.(1999)).

Mixed-bred mares and geldings of various ages used in this study were shown to be WN virus and SLE virus antibody-negative by ELISA and PRNT. Four horses were injected i.m. with a single dose (1,000 µg/1,000 µl in PBS, pH 7.5) of pCBWN plasmid. Serum specimens were collected every other day for 38 days prior to virus challenge, and the WN virus specific antibody response was evaluated by MAC- or IgG ELISA and PRNT.

Two days prior to virus challenge, 12 horses (4 vaccinated and 8 control) were relocated into a bio-safety level (BSL)-3 containment building at the Colorado State University. The eight unvaccinated control horses were the subset of a study that was designed to investigate WN virus induced pathogenesis in horses and the potential of horses to serve as amplifying hosts. Horses were each challenged by the bite of 14 or 15 *Aedes albopictus* mosquitoes that had been infected by NY99-6425 or BC787 virus 12 days prior to horse challenge. Mosquitoes were allowed to feed on horses for a period of 10 min. Horses were examined for signs of disease twice daily. Body temperature was recorded, and serum specimens collected twice daily from days 0 (day of infection) to 10, then once daily through day 14. Pulse and respiration were recorded daily after challenge. The collected serum samples were tested by plaque titration for detection of viremia, and by MAC- or IgG ELISA and PRNT for antibody response.

No systemic or local reaction was observed in any vaccinated horse. Individual horse sera were tested by PRNT. Vaccinated horses developed Nt antibody greater than

or equal to 1:5 between days 14 and 31. End point titers for vaccinated horses, #5, #6, #7, and #8, on day-37 (two days prior to mosquito challenge) were 1:40, 1:5, 1:20, and 1:20, respectively. Horses vaccinated with the pCBWN plasmid remained healthy after virus challenge. None of them developed a detectible viremia or fever from days 1 to 14. All unvaccinated control horses became infected with WN virus after exposure to infected mosquito bites. Seven of the eight unvaccinated horses developed viremia that appeared during the first 6 days after virus challenge. Viremic horses developed Nt antibody between day-7 and day-9 after virus challenge. The only horse from the entire study to display clinical signs of disease was horse #11, which became febrile and showed neurologic signs beginning 8 days after infection. This horse progressed to severe clinical disease within 24 hours and was euthanized on day 9. Four representing horses, #9, 10, 14 and 15, presenting viremia for 0, 2, 4, or 6 days, were selected and used as examples in this example. Virus titers ranged from $10^{1.0}$ PFU/ml of serum (in horse #10), the lowest level detectable in our assay, to $10^{2.4}$/ml (in horse #9). Horse #14 did not develop a detectible viremia during the test period. However, this horse was infected by the virus, as evidenced by Nt antibody detected after day 12.

Anamnestic Nt antibody response was not observed in vaccinated horses as evidenced by the gradual increase in Nt titer during the experiment. Pre-existing Nt antibody in the vaccinated horse prior to mosquito challenge could suppress initial virus infection and replication. Without virus replication, the challenge virus antigen provided by infected mosquitoes may not contain a sufficient antigen mass to stimulate anamnestic immune response in the vaccinated horse. All vaccinated horses were euthanized at 14 days after virus challenge. Gross pathological and histopathological lesions indicative of WN viral infection were not observed.

<u>Example 12. Preparation of recombinant plasmids containing coding sequences for yellow fever virus (YFV) or St. Louis encephalitis virus (SLEV) prM and E proteins</u>. A strategy similar to constructing the pCDJE2-7 recombinant plasmid was used to prepare YFV and SLEV recombinant plasmids. Genomic RNA was extracted

from 150 μL of YFV strain TRI-788379 or SLE strain 78V-6507 virus seeds using Q1Aamp™ Viral RNA Kit (Qiagen, Santa Clarita, CA.). The viral RNA was used as a template for amplification of YFV or SLEV prM and E gene coding regions. Primers YFDV389 (nucleotide sequence, SEQ ID NO:4; amino acid sequence, SEQ ID NO:5), cYFDV2452 (SEQ ID NO:6), SLEDV410 (nucleotide sequence, SEQ ID NO:7; amino acid sequence, SEQ ID NO: 8) and cSLEDV2449 (SEQ ID NO:9) were used to generate the corresponding recombinant nucleic acids as described above for the preparation of the JEV and WNV recombinant plasmids. RT-PCR amplified cDNA, digested with KpnI and NotI enzymes, was inserted into the KpnI-NotI site of a eukaryotic expression plasmid vector, pCDNA3 (Invitrogen). Both strands of the cDNA were sequenced and verified for identity to sequences from YFV strain TRI-788379 or SLEV strain 78V-6507. Recombinant plasmids pCDYF2 and pCDSLE4-3, which contained the nucleotide sequences of the prM and E coding regions for YFV or SLEV, respectively, were purified using an EndoFree™ Plasmid Maxi Kit (Qiagen), and used for *in vitro* transformation or mouse immunization.

YFV or SLEV specific antigens were expressed in COS-1 cells transformed by pCDYF2 or pCDSLE4-3, respectively. The level of expressed proteins was similar to a YFV- or SLEV-infected COS-1 cell control. As in the JEV model, COS-1 cell lines transformed by vectors bearing genes for the viral antigens were obtained which constitutively express YFV or SLEV antigenic proteins. Epitope mapping by IFA using a panel of YFV or SLEV E-specific Mabs indicated that the authentic E protein was expressed by the pCDYF2- or pCDSLE4-3-transformed COS-1 cells. A preliminary study indicated that 100% of three week-old female, ICR mice seroconverted after intramuscular inoculation with a single dose of 100 μg/100 μL of pCDSLE4-3 plasmid in deionized water.

<u>Example 13. Preparation of recombinant plasmids containing coding sequences for St. Louis encephalitis virus prM and E antigens with JEV signal sequence</u>. Genomic RNA was extracted from 150 μL of Vero cell culture medium infected with

MSI-7 strain of St. Louis encephalitis virus using the QIAamp™ Viral RNA Kit (Qiagen, Santa Clarita, CA). Extracted RNA was eluted and suspended in 80 µl of nuclease-free water, and used as a template for the amplification of St. Louis encephalitis virus prM and E gene coding sequences. Primer sequences were obtained from the work of Trent et al. (*Virology* 156: 293-304 (1987)). A cDNA fragment containing the genomic nucleotide region was amplified by the reverse transcriptase-polymerase chain reaction (RT-PCR). Restriction site AfeI was engineered at the 5' terminus of the cDNA by using amplimer SLE463 (SEQ ID NO:30). An in-frame translation termination codon , followed by a NotI restriction site was introduced at the 3' terminus of the cDNA by using amplimer cSLE2447 (SEQ ID NO:31). The RT-PCR product was purified by a QIAquick™ PCR Purification Kit (Qiagen).

The double-stranded amplicon, produced by use of the two amplimers above (SEQ ID NO:30 and SEQ ID NO:31), was digested with AfeI and NotI enzymes to generate a 2004 fragment of DNA (463 to 2466nt), and inserted into the AfeI and NotI sites of a pCBJESS-M vector to form pCBSLE (nucleotide sequence, SEQ ID NO:21; amino acid sequence, SEQ ID NO:22). The pCBJESS-M was derived from the pCBamp plasmid, that contained the cytomegalovirus early gene promoter and translational control element and an engineered, modified JE signal sequence element (SEQ ID NO:27). The JE signal sequence element comprises the modified JE signal sequence at –4 (Cys to Gly) and –2 (Gly to Ser) position in the original pCBJESS plasmid.

Automated DNA sequencing using an ABI prism 377 Sequencer (Applied Biosystems/Perkin Elmer, Foster City, CA) was used to confirm that the recombinant plasmid had a correct prM and E sequence as defined by Trent et al. (*Virology* 156: 293-304 (1987)).

<u>Example 14. Preparation of recombinant plasmids containing coding sequences for yellow fever virus (YFV) prM and E proteins with JEV signal sequence</u>. Genomic

RNA was extracted from 150 µL of Vero cell culture medium infected with 17D-213 strain of yellow fever virus using the QIAamp™ Viral RNA Kit (Qiagen, Santa Clarita, CA). Extracted RNA was eluted and suspended in 80 µl of nuclease-free water, and used as a template for the amplification of yellow fever virus prM and E gene coding sequences. Primer sequences were obtained from the work of dos Santos et al. (*Virus Research* 35: 35-41 (1995)). A cDNA fragment containing the genomic nucleotide region was amplified by the reverse transcriptase-polymerase chain reaction (RT-PCR). Restriction site AfeI was engineered at the 5' terminus of the cDNA by using amplimer YF482 (SEQ ID NO:28). An in-frame translation termination codon, followed by a NotI restriction site was introduced at the 3' terminus of the cDNA by using amplimer cYF2433 (SEQ ID NO:29). The RT-PCR product was purified by a QIAquick™ PCR Purification Kit (Qiagen).

The double-stranded amplicon, produced by use of the two amplimers above (SEQ ID NO:28 and SEQ ID NO:29), was digested with AfeI and NotI enzymes to generate a 1971 fragment of DNA (482 to 2452nt), and inserted into the AfeI and NotI sites of a pCBJESS-M vector to form pCBYF (nucleotide sequence, SEQ ID NO:23; amino acid sequence, SEQ ID NO:24). The pCBJESS-M was derived from the pCBamp plasmid, that contained the cytomegalovirus early gene promoter and translational control element and an engineered JE signal sequence element (SEQ ID NO:27). The JE signal sequence element comprises the modified JE signal sequence at –4 (Cys to Gly) and –2 (Gly to Ser) position of JESS in the pCBJESS plasmid.

Automated DNA sequencing using an ABI prism 377 Sequencer (Applied Biosystems/Perkin Elmer, Foster City, CA) was used to confirm that the recombinant plasmid had a correct prM and E sequence as defined by dos Santos et al. (*Virus Research* 35: 35-41 (1995)).

Example 15. Preparation of recombinant plasmids containing coding sequences for Powassan virus prM and E antigens with JEV signal sequence. Genomic RNA was

extracted from 150 µL of Vero cell culture medium infected with LB strain of Powassan virus using the QIAamp™ Viral RNA Kit (Qiagen, Santa Clarita, CA). Extracted RNA was eluted and suspended in 80 µl of nuclease-free water, and used as a template for the amplification of Powassan virus prM and E gene coding sequences. Primer sequences were obtained from the work of Mandl et al. (*Virology* 194: 173-184 (1993)). A cDNA fragment containing the genomic nucleotide region was amplified by the reverse transcriptase-polymerase chain reaction (RT-PCR). Restriction site AfeI was engineered at the 5' terminus of the cDNA by using amplimer POW454 (SEQ ID NO:25). An in-frame translation termination codon, followed by a NotI restriction site was introduced at the 3' terminus of the cDNA by using amplimer cPOW2417 (SEQ ID NO:26). The RT-PCR product was purified by a QIAquick™ PCR Purification Kit (Qiagen).

The double-stranded amplicon, produced by use of the two amplimers above (SEQ ID NO:25 and SEQ ID NO:26), was digested with AfeI and NotI enzymes to generate a 1983 bp fragment of DNA (454 to 2436nt), and inserted into the AfeI and NotI sites of a pCBJESS-M vector to form pCBPOW (nucleotide sequence, SEQ ID NO:19; amino acid sequence, SEQ ID NO:20). The pCBJESS-M was derived from the pCBamp plasmid, that contained the cytomegalovirus early gene promoter and translational control element and an engineered JE signal sequence element (SEQ ID NO:27). The JE signal sequence element comprises the modified JE signal sequence at –4 (Cys to Gly) and –2 (Gly to Ser) position of JESS in the pCBJESS plasmid.

Automated DNA sequencing using an ABI prism 377 Sequencer (Applied Biosystems/Perkin Elmer, Foster City, CA) was used to confirm that the recombinant plasmid had a correct prM and E sequence as defined by Mandl et al. (*Virology* 194:173-184, (1993)).

<u>Example 16. Preparation of plasmids containing coding sequences for dengue serotype 2 structural proteins</u>. Procedures such as those carried out for other

flaviviruses (see Examples 1, 9 and 12-15) are to be followed to prepare vectors including nucleic acid TU's for dengue serotype 2 antigens. According to the examples, the amplimers used for construction of the vectors may be chosen to engineer the normal dengue virus signal sequence or they may be chosen so as to engineer a signal sequence from another flavivirus, such as a modified Japanese encephalitis virus signal sequence.

A plasmid containing the dengue serotype 2 gene region from prM to E is to be constructed. The dengue serotype 2 prM and E genes (Deubel et al., *Virology* 155:365-377 (1986); Gruenberg et al., *J. Gen. Virol.* 69: 1301-1398 (1988); Hahn et al., *Virology* 162:167-180 (1988)) are to be ligated into a plasmid such as pCDNA3, and then excised and cloned into vectors such as pCBamp, pCEP4, pREP4, or pRc/RSV (supplied by Invitrogen, Carlsbad, CA) to enable expression. If necessary, a dengue serotype 2 virus-specific sequence encoded in a cDNA sequence may be amplified using a procedure such as the polymerase chain reaction (PCR). Alternatively, if the viral RNA is the source of the gene region, a DNA sequence may be amplified by a RT-PCR procedure. A DNA fragment including an initiation codon at the 5' end, and a termination codon at the 3' end is to be cloned into an expression vector at an appropriate restriction nuclease-specific site, in such a way that the cytomegalovirus (CMV) immediate early (IE) promoter, an initiation codon, and a terminator, are operably linked to the dengue serotype 2 virus sequence.

<u>Example 17. Vaccination of mice using a dengue serotype 2 DNA vaccine</u>. The dengue serotype 2 nucleic TU vaccine encoding the gene region from prM to E prepared in Example 16 is to be suspended in a suitable pharmaceutical carrier, such as water for injection or buffered physiological saline, and injected intramuscularly into groups of weanling mice. Control groups receive a comparable plasmid preparation lacking the dengue serotype 2 specific genes. The generation of dengue serotype 2-specific antibodies, and/or of dengue serotype 2-specific immune system cytotoxic cells, is to be assessed at fixed intervals thereafter, for example at weekly intervals. At

about two to four months after administration of the nucleic acid TU vaccine, mice are to be challenged with dengue serotype 2 virus. Levels of viremia are to be assessed at appropriate intervals thereafter, such as every second day. Passive protection by maternal antibody is to be assessed as indicated in Example 8.

Table 1. Transient expression of JE prM and E proteins by various recombinant plasmids in two transferred cell lines.

Vector					Recombinant Plasmid	IFA intensity/percentage of antigen-positive cells*	
	Promotor	Intron	Poly (A)	ORI		COS-1	COS-7
pCDNA3	CMV	No	BGH	SV40	pCDJE2-7	3+/40	3+/35
pCBamp	CMV	No	BGH	No	pCBJE1-14	3+/45	nd
pC1Bamp	CMV	Yes	BGH	No	pC1BJES14	3+/39	nd
pCEP4	CMV	No	SV40	OriP	pCEJE	2+/4	2+/3
pREP4	RSV	No	SV40	OriP	pREJE	1+/3	1+/2
pRe/RSV	RSV	No	BGH	SV40	pRCJE	1+/3	1+/3
pCDNA3	CMV	No	BGH	SV40	pCDNA3/CAT	-	-

*Various cell lines were transformed with pCDNA3/CAT (negative control), pCDJE2-7, pCBJE1-14, pC1BJES14, pCEJEm pREJE, or pRCJE, Cells ere trypsinized 48 hours later and tested by an indirect immunofluorescent antibody assay (IFA) with JE virus-specific HIAF. Data are presented as the intensity (scale of 1+ to 4+) and the percentage of IFA positive cells. The pCDNA3/CAT transformed cells were used as the negative control.

Table 2. Characterization of proteins expressed by a pCDJE2-7 stably transformed clone (JE-4B) of COS-1 cells with JE virus-reactive antibodies.

Mab or antiserum	Biological Activity of Mab		Immunofluorescent intensity of cells	
	Specificity	Biological Function	JEV infected	4B
Mab:				
MC3	JEV Specific		2+	2+
2F2	JEV Specific	HI, N	4+	4+
112	JEV Specific		4+	4+
503	JEV Specific	N	4+	3+
109	Subgroup	HI	2+	1+
N.04	Subgroup	HI, N	3+	4+
201	Subgroup		1+	1+
203	Subgroup		4+	3+
204	Subgroup		2+	2+
301	Subgroup	HI	2+	2+
504	Flavivirus		4+	4+
6B6C-1	Flavivirus		2+	2+
3B4C-4	VEE		-	-
H1AF:				
Anti-JEV			4+	3+
Anti-WEE			-	-
PBS			-	-

Table 3. Persistence of the immune response in mice immunized with pCDJE2-7 or JE-VEX vaccine.

	ELISA Titer (log_{10})						$PRNT_{90\%}$ Titer		
	3 wks	6 wks	9 wks	23 wks	40 wks	60 wks*	3 wks	6 wks	9 wks
1x pCDJE2-7	2.6-3.2	3.8-5.0	3.8-4.4	>3.2	>3.2	2.4, 2.4, 3.8, 4.4	<20	20	40-160
2x pCDJE2-7	2.6-3.8	4.4	3.8-4.4	>3.2	>3.2	2.6, 3.8, 3.8	<20	20-40	40-160
2x JE-VAX	2.6-3.8	4.4-5.0	3.8-5.6	>3.2	>3.2	<2,<2,<2,4.4	<20	20-40	20-160
2x pCDNA3/CAT	<2	<2	<2	ND	ND	<2	<20	<20	<20

Mice were inoculated with 1 or 2, 100 µg/dose plasmid DNA, or 1/5 human dose of JE-VAX vaccine. Sera were collected for testing prior to the second immunization.

* Individual serum titers.

Table 4. The age-dependent percent seropositive rate in mice following vaccination with various JEV vaccines.

	3-day old		3-week old	
	3 weeks PV	7 weeks PV	3 weeks PV	7 weeks PV
JE-VAX	0	0	100	100
pCDNA3/CAT	0	0	0	0
pCDJE2-7	40	60	90	90
pC1BJES14	10	60	80	100
pCBJE1-14	80	100	100	100

Table 5. Protection from JEV challenge in 8 week old mice following vaccination at 3 days old with various JEV vaccines.

Vaccine	Pre-challenge JEV seroconversion	Days post-challenge survival rate (%)				
		6	7	8	9	21
JE-VAX	0	100	100	60	40	40
pCDNA3/CAT	0	100	80	30	30	30
pCDJE2-7	60	100	100	100	100	100
pC1BJES14	60	100	100	100	100	100
pCBJE1-14	100	100	100	100	100	100

Table 6. Evaluation of the ability of maternal antibody from JEV-nucleic acid-vaccinated female mice to protect their pups from fatal JEV encephalitis.

Vaccinated mother		JEV challenged pups		
Vaccine	$PRNT_{90\%}$	Challenge age (days)	No. survival[1]	ELISA[2]
1 x pCDJE2-7	40	4	0/11	
2 x pCDJE2-7	80	4	12/12	12/12
2 x JE-VAX	20	3	0/16	
2 x pCDNA-3/CAT	<10	5	0/14	
1 x pCDJE2-7	20	15	5/11	5/5
2 x pCDJE2-7	40	14	8/12	7/8
2 x JE-VAX	80	13	5/5	5/5
2 x pCDNA-3/CAT	<10	14	0/14	

Mice were inoculated intramuscularly with 1 or 2, 100 μg dose of plasmid DNA, or subcutaneously with two, 1/5 human dose of JE-VAX vaccine. Sera were collected 9 weeks post-vaccination for PRNT testing prior to mating with non-immune male.

[1]: No Survivors/total for each litter.

[2]: Number of JEV ELISA-antibody-positive animals (titer ≥ 1:400)/No. of survivors; sera were collected for testing 12 weeks after challenge.